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Dead Western White Pine: Characteristics, Product Recovery, and Problems Associated With Utilization

Thomas A. Snellgrove and James M. Cahill

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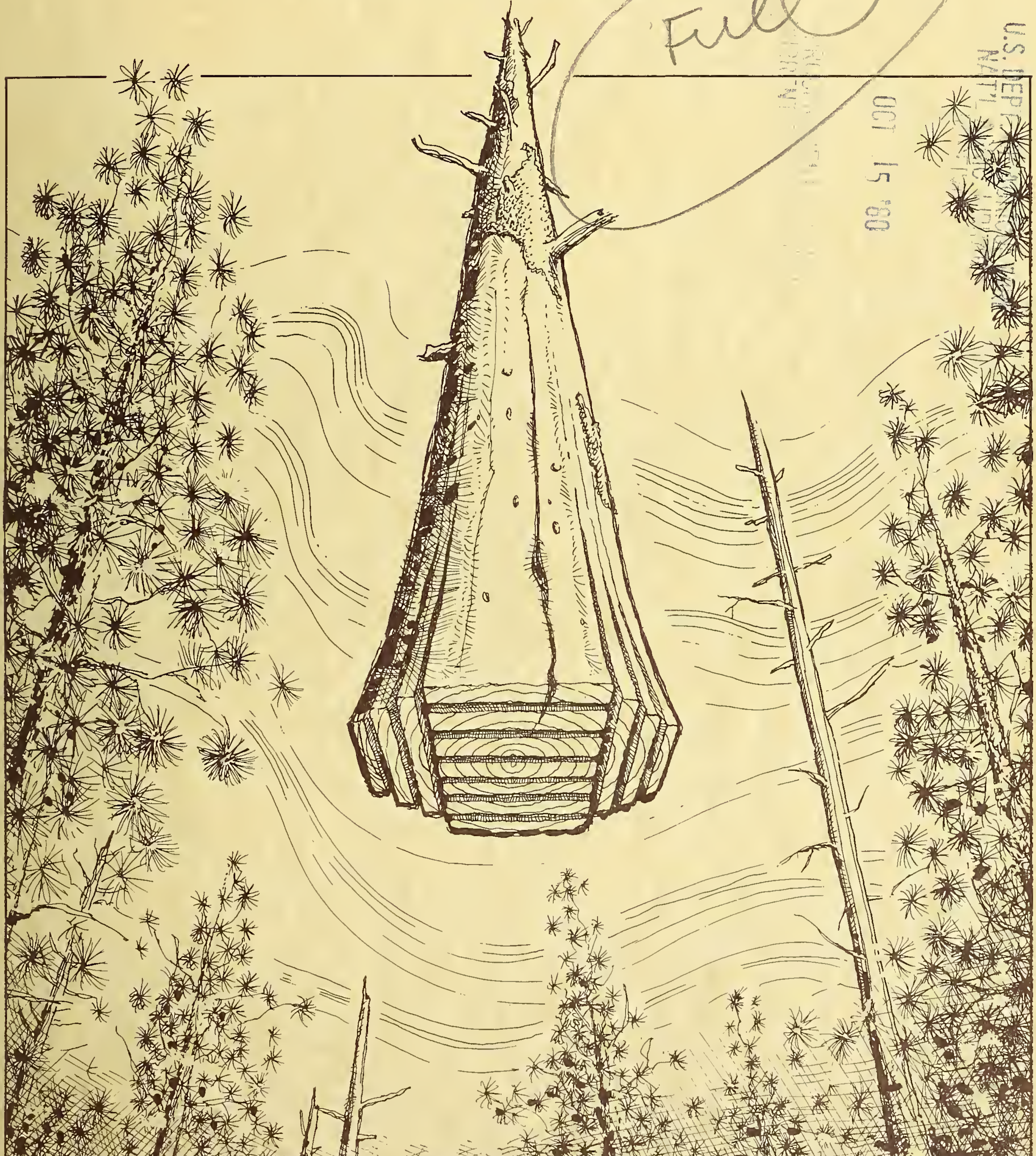

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Authors

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Metric Equivalents

1 inch	=	2.540 centimeters
1 foot	=	0.305 meter
1 cubic foot	=	0.028 cubic meter
1 pound	=	0.454 kilogram

Foreword

This research reflects the team effort of USDA Forest Service scientists and support staff to determine the value of standing dead timber. The authors recognize the contribution of fellow scientists in field techniques and data collection and analysis. Special credit is given Thomas D. Fahey for his suggested treatment of the data.

This and related research on the potential for product recovery by the Timber Quality Project of the Pacific Northwest Forest and Range Experiment Station have been factors in expanded utilization of extensive volumes of dead softwood timber in the West.

Richard O. Woodfin Jr.

RICHARD O. WOODFIN, JR.
Project Leader

Contents

Dead Western White Pine: Characteristics, Product Recovery, and Problems Associated With Utilization

Reference Abstract

Snellgrove, Thomas A., and James M. Cahill.
1980. Dead western white pine: characteristics, product recovery, and problems associated with utilization. USDA For. Serv. Res. Pap. PNW-270, 63 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

When a western white pine (Pinus monticola Dougl. ex D. Don) tree dies, it undergoes a series of physical changes. The effects of these changes on product recovery are evaluated. Tabular information and prediction equations provide the tools necessary for using this resource.

KEYWORDS: Dead timber, lumber recovery, lumber yield, wood utilization, deterioration (wood), western white pine (dead), Pinus monticola.

Research Summary
Research Paper PNW-270
1980

Millions of board feet of western white pine (Pinus monticola Dougl. ex D. Don) are killed annually by white pine blister rust (Cronartium ribicola) and the mountain pine beetle (Dendroctonus ponderosae); yet less than 10 percent of this mortality is currently salvaged. This report provides tools for resource managers and the forest products industry to make decisions that can increase utilization of this dead material. It also provides a framework and guidelines for future research on dead timber.

When a tree dies, it undergoes a series of changes that affect product recovery. These changes include staining, heart checking (splitting), surface checking, weathering, and a general increase in sap rots and wood borer damage. Estimated defect varies substantially, depending on the types of defects and the scaling system used for measurement. Estimates were highest when net Scribner and cubic product potential were the basis for measurement; net cubic showed the lowest defect percents. Net Scribner scale and cubic product potential overestimated the impact of defects on actual product volume; net cubic underestimated the impact.

Even though overrun based on net Scribner is the most common method of representing product recovery in the West, for our study it was the poorest system. Cubic recovery percent and lumber recovery factor best represent the relationship of sawn product volume to log volume. In both systems, when lumber recovery was based on either gross or net cubic scale, recovery decreased from live through the classes of dead logs.

There is a substantial difference in lumber quality between live and dead timber. Live trees produce a high percentage of No. 2 Common and Better and Shop grades, whereas older dead material produces more Nos. 4 and 5 Common. Loss of lumber grade was greatest in highest quality logs because there was more grade to lose. Lumber width also decreased as time since death increased. The average value of lumber produced decreased by about 50 percent from live trees to the oldest dead class. This decrease in value is a reflection of both lower quality lumber and narrower widths.

Losses in log values in dead timber result from combined losses of lumber volume and value. The average value decreases from live logs through the oldest dead logs. Log value also decreases with a decrease in diameter; consequently, both size and deterioration should be considered when values of logs are considered.

As wood dries it becomes more brash; consequently, breakage increases with time since death. The total dollar losses in dead trees are a combination of the losses in lumber volume and value plus the effect of increased breakage.

Six general equations were tested for predicting product recovery and value. The general equation, $\hat{y}=b_0+b_1x_i+b_2/x_i+b_3/x_i^2$, performed best as measured by R^2 and standard error of the estimate.

A system based of one live class and three dead classes of material balanced ease of application with refined accuracy. For this four-class system, the advantage of using classes exceeded the advantage of regressing over diameter, when evaluated on the basis of variation accounted for.

Introduction

The United States contains an estimated 21 billion board feet of western white pine (Pinus monticola Dougl. ex D. Don) sawtimber (USDA Forest Service 1973). More than 300 million board feet is killed annually by white pine blister rust (Cronartium ribicola) and mountain pine beetle (Dendroctonus ponderosae).[1/] Less than 10 percent of this annual mortality is salvaged (USDA Forest Service 1973).

The opportunity to use this resource depends on several considerations: availability of raw material, market value and acceptance of products, and total costs of producing the products. Before these considerations are addressed, however, we must know the expected product recovery from the dead material. We know that there will be losses in product volume and quality of dead trees compared with live trees. We know that breakage increases in felling and handling. Likewise, how the raw material is measured will have an impact on estimated product recovery and, therefore, on appraised values. This paper is based on a study of western white pine in Idaho and provides information and insight into the relationship between product recovery, defects that develop after death of a tree, and scaling systems. With this information, resource managers and the forest products industry can make economic decisions about the profitable use of dead western white pine.

This report will also provide a framework and guidelines for future research on dead timber. The problems we encountered in analyzing results in this study led us to try techniques not commonly used or reported in reports of product recovery. See "Analytical Procedures" for these techniques.

[1/] Unverified data provided by the Clearwater National Forest, September 4, 1973.

Procedures

Methodology of the study will be discussed in general terms here. More details on the procedures can be found in appendix 1.

Our sample consisted of 194 trees from the Clearwater National Forest in Idaho. Individual trees were selected on the basis of size and stage of deterioration. Efforts were taken to ensure that the sample was representative of the size and quality of western white pine trees from 9- to 34-inch d.b.h. No larger trees were selected; consequently, application of these results should be restricted to this d.b.h. range. Initially, the sample trees were placed in one of six deterioration classes. Subsequent analysis resulted in four deterioration classes:[2/]

Live:	living green trees
Class I:	dead trees (some needle retention)
Class II:	dead trees (no needles --90-percent and greater bark retention[3/])
Class III:	dead trees (no needles--less than 90-percent bark retention in merchantable bole)

Distribution of trees by deterioration class and d.b.h. is shown in table 1.

[2/] A detailed explanation of how the original deterioration classes were selected appears in appendix 1; how we arrived at the final four classes is presented in "Analytical Procedures."

[3/] Percent of bark retention was determined by ocular estimate based on the linear footage of the tree to a 6-inch top. No attempt was made to estimate the bark retained as a percentage of surface area of the tree.

Results and Discussion

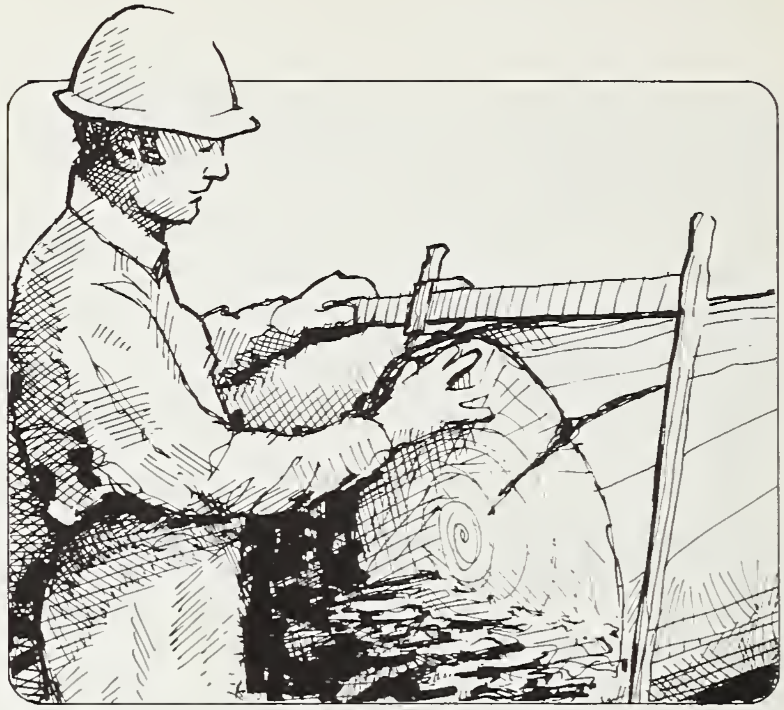


Table 1--Distribution of western white pine sample trees by deterioration class

Deterioration class	Number of trees	D.b.h. Range	D.b.h. Average[1]
		- - - Inches - - -	
Live	17	10-33	22.5
Class I	61	9-29	20.3
Class II	43	9-34	21.2
Class III	73	9-31	20.5
Total or average	194	9-34	20.8

[1]Quadratic mean.

Sample trees were felled and bucked and the subsequent logs identified by tree and log number. Bucked logs were scaled by USDA Forest Service scalers and then processed through a double-cut bandmill. The final lumber tally was equivalent to a shipping tally. The resultant recovery information was the basis for the analysis in this report.

Log Information

One objective of this paper is to provide resource managers and the forest products industry with the necessary tools to make economic decisions that will increase the utilization of dead western white pine. A primary tool used by both groups is an estimate of product recovery from dead material. To understand product recovery requires an understanding of the relationship between product recovery and two additional factors: the nature of the defects developing after a tree dies and the scaling procedures resulting in estimates of these defects. With an understanding of the relationship between defects, measurements of these defects, and product recovery, users can successfully apply results of the study.

This section will cover:

Defect, with emphasis on development of defect, estimation of defect, and the relationship of these factors to product recovery.

Lumber volume recovery, with emphasis on various methods of presenting recovery ratios.

Lumber yields, with emphasis on lumber grade yields, dimensions, and values.

Log values, which combine the effect of product volume and quality on total log values.

DEFECT

Development of Defect

Physiological defects occur naturally in western white pine trees. In addition to this inherent defect, dead timber is further deteriorated by stain, checks,[4] sap decay, insect damage, and weathering.[5]

[4] Checks are splits in the bole of a tree caused by differential drying stresses.

[5] Weathering is general deterioration of the surface of a tree primarily caused by checking and oxidation.

When a tree dies, it undergoes a series of changes that may affect the volume and quality of products (figs. 1-5). Western white pine sapwood stains immediately. Also, the tree begins drying which eventually sets up stresses that are released in the form of splits in the bole of the tree. As the tree dries, the wood also loses plasticity and becomes more brash (Wangaard 1950, Panshin and DeZeeuw 1964). At later stages of deterioration, surface checking, weathering, sap rot, and damage from wood borers increase and can render the outer portion of the tree unusable for products. Wright and Harvey (1967) show graphically and discuss similar deterioration in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

Deterioration is controlled by environmental influences, such as precipitation, elevation, exposure, slope, and soil. These influences control moisture and temperature conditions, hastening or slowing the rate of deterioration. Not only do moisture and temperature conditions vary from area to area, they also vary up and down the bole of a dead tree. Moist stream bottoms, south exposures, and high elevation have a different effect on deterioration than do exposed ridgetops, north exposures, and low elevations. Basal portions of trees and trees retaining bark present different conditions than tops and trees devoid of bark. When considering two main forms of deterioration--checking and sap decay--we can generalize that any set of conditions promoting drying will increase checking and retard fungal activity. The opposite will be true for trees or sections of trees retaining moisture. Stain appeared to be reasonably constant throughout all the dead trees.

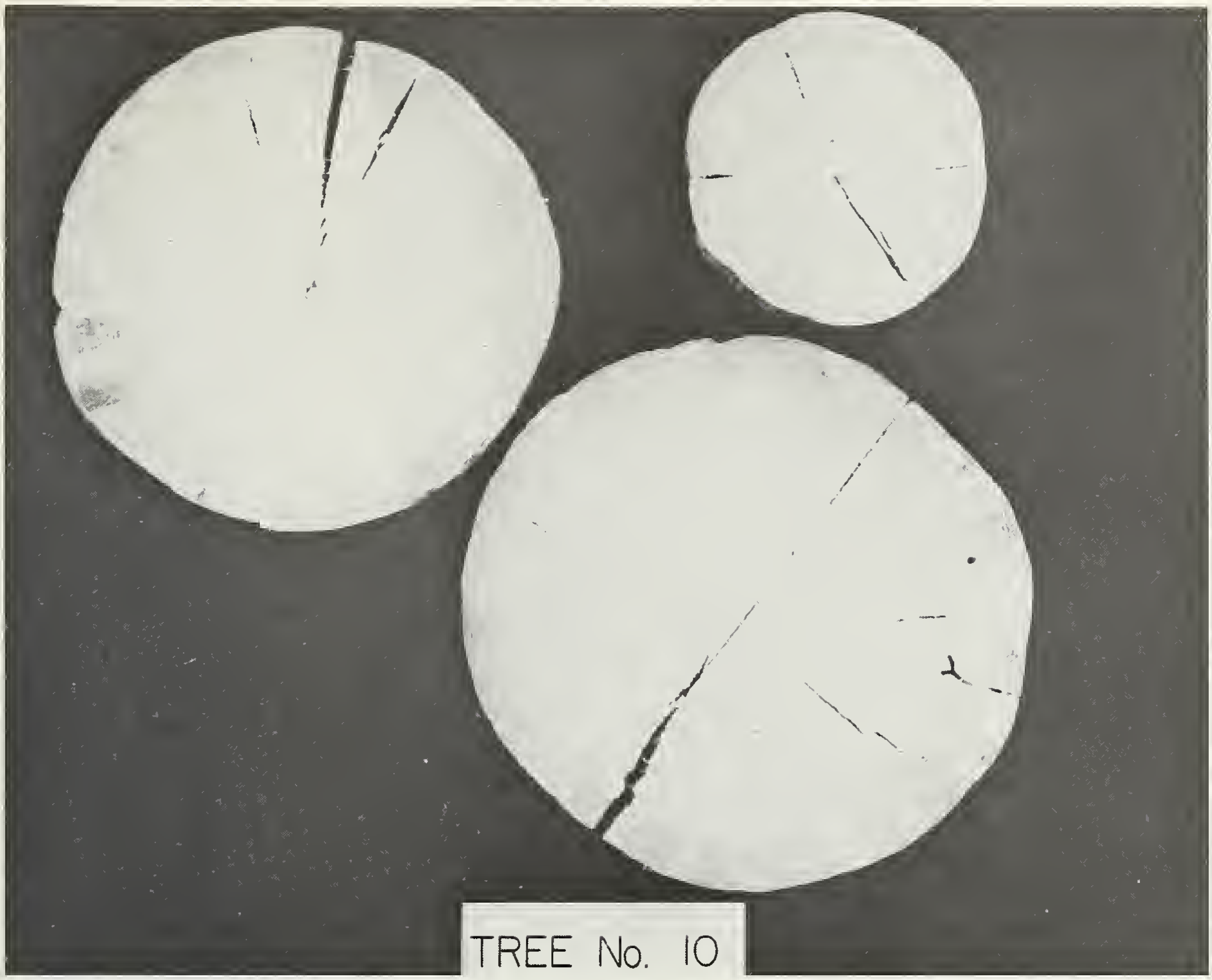
Figure 1.--Typical live western white pine bolts.

The relationship of environmental factors to deterioration is complex, and it was not in the scope of this study to analyze environmental factors. Since all these conditions can occur over the range of a single timber sale, understanding the basic relationships between environmental factors and deterioration is as important as the specific rates of deterioration.

Defect Estimation

Estimation of defect varies substantially, depending on the scaling system used. This variation is a function of both the types of defects and the vagaries of the measurement system. We will show defect percents based on three methods of estimation and explain why these estimates vary. We will also point out likely reasons for the general increase in defect in logs from dead trees compared with logs from live trees.

A



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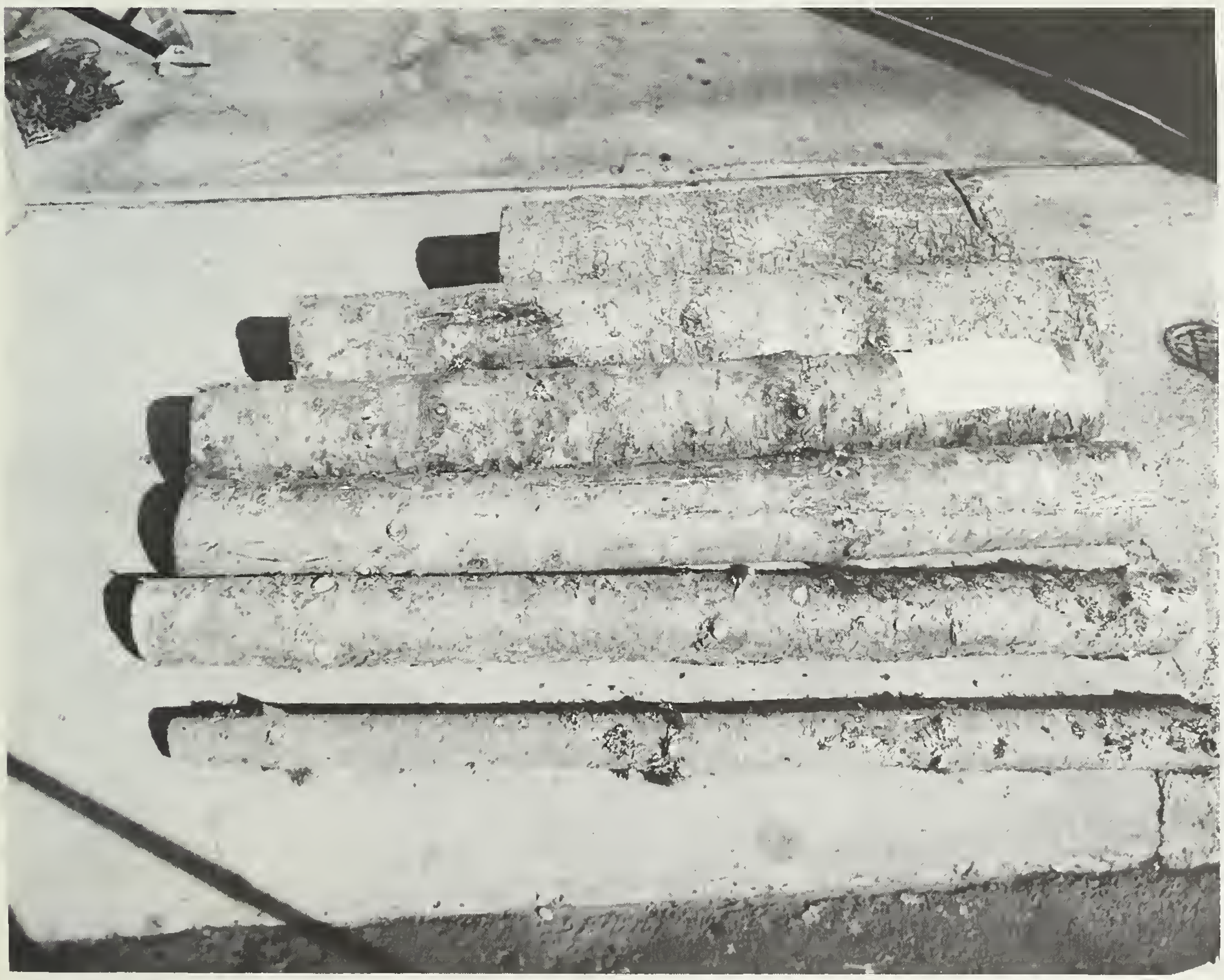
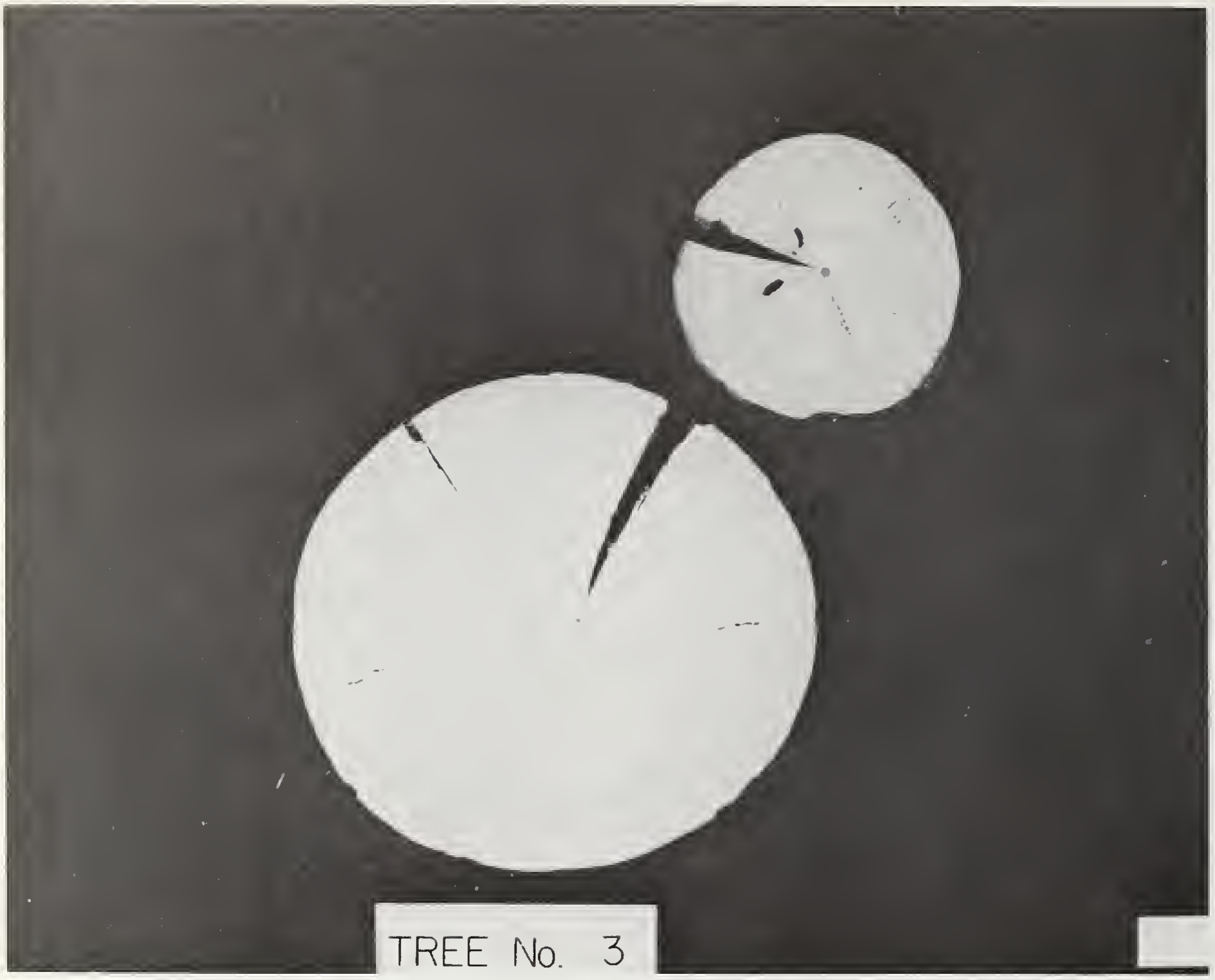


Figure 2.--Typical deterioration of class I western white pine bolts and disks: A, shows shows initial checking in the disks. B, shows little sloughing of bark on the bolts even though the bark has broken from the cambium.

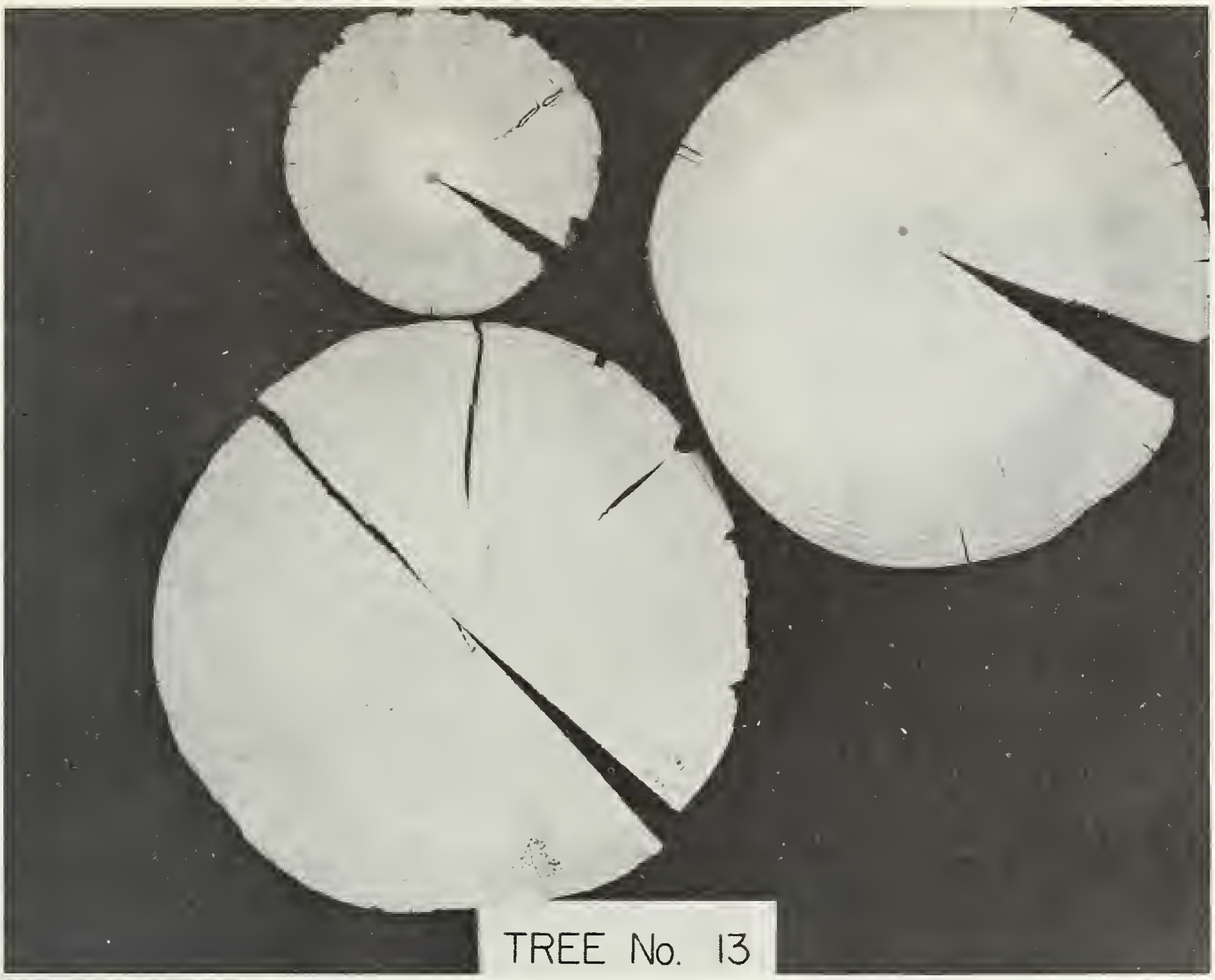
A



B

Figure 3.--Typical deterioration of class II western white pine bolts and disks: A, shows expanded width of checks in disks, but there is little surface deterioration on the outer portions of the disks. B, shows bark beginning to slough.

A



B

Figure 4.--Typical deterioration of class III western white pine bolts and disks: A, disks show little change in primary checking relative to class II, but surface deterioration from weathering, checking, oxidation, and sap rots are evident. B, bolts show absence of bark.

Figure 5.--Typical deterioration in standing class III western white pine tree (same as fig. 4). Note wormholes, spiral checking, and general deterioration of the surface.

Table 2 shows defect percents based on net Scribner scale, net cubic scale, and product potential cubic scale. Definitions and procedures for applying these scales are shown in appendix 1.

It is apparent from table 2 that there is a substantial difference in defect depending on how it is estimated. Each scaling system has a different purpose. The purpose of each system will explain differences between methods of estimating defects:

Net Scribner reduces estimates of board-foot recovery for defects that are supposed to reduce lumber tally volume.

Net cubic reduces estimates of logs for voids, soft rots, and charred wood. It is intended to predict the volume of a log that is suitable to produce a solid chip. It does not reduce volumes for such defects as sweep, crook, shake, checks, splits, incipient decay, or certain advanced decays, such as white speck (*Fomes pini*).

Product potential cubic is similar to net Scribner scale in that it reduces estimates of log volume for defects that are supposed to reduce lumber tally volume; however, it is based on cubic rather than board-foot volume.

We can now show why the estimates of defect in table 2 increase in each deterioration class within each system. Figures 1-5 pictorially show these changes.

Net Scribner. The increase from 6.7 to 48.7 percent represents deductions made for checking. Deductions for continued checking plus the onset of sap rots are responsible for the increase from class I to class II logs. These defects plus heavy sap decay and weathering contribute to the high defect in the class III sample.

Table 2--Defect expressed as a percent of gross Scribner scale and gross cubic scale for woods-length logs of western white pine [1/]

Deterioration class	Number of logs	Net Scribner defect [2/]	Net cubic defect [3/]	Product potential cubic defect [3/]
		- - - - - - - -	Percent	- - - - - - - -
Live	53	6.7	0.9	8.2
Class I	200	48.7	3.0	39.5
Class II	132	79.0	5.2	59.8
Class III	214	93.8	11.6	80.4
Total or average	599	67.8	6.4	55.8

[1/] Defect percent is shown as arithmetic average adjusted to a common diameter base between classes. It is based on regression analysis. The formula used to calculate defect percent is (gross scale minus net scale/gross scale) (100).

[2/] Based on woods-length logs as scaled by USDA Forest Service scalers applying National Forest Service Log Scaling Handbook rules as of 1974.

[3/] Based on woods-length logs as scaled by USDA Forest Service scalers applying the proposed National Forest Service Cubic Scaling Handbook rules as of June 1974. Diameters recorded in accordance with cubic scaling handbook; length is actual log length to nearest 1/10 of a foot.

Net cubic. Since net cubic does not consider checks as deductions, the defect percents are lower than for Scribner. They ranged from 0.9 percent for the live sample to 11.6 for the class III logs. The differences in defect percent between classes is primarily due to the inception of sap decays plus weathering in the class II and III logs.

Product potential cubic. The high estimates of defect in this scaling system show much the same pattern as net Scribner scale, and the reasons for the increases in estimates of defects are essentially the same as for Scribner.

We have established in table 2 that estimates of defect differ according to the system used for estimation. We also know that defect percents increased from live logs through the dead classes. We will now discuss how these estimates of defects relate to product recovery.

Relationship of Defect, Scale, and Product Recovery

For our purposes, estimates of defects are most important in terms of product recovery; product recovery can only be explained in terms of how the logs were measured. The estimate of defect which is deducted from total gross scale is one of

the major variables affecting the accuracy of product estimates. This section illustrates the relationship of product recovery to defect and scale.

Estimates of defects are generally expressed in terms of defect percent (table 2). Product volume, however, is actually predicted from and should be correlated with the percentage of the log that is sound. Percent sound is the complement of defect percent; e.g., 30-percent defect can be shown as 70 percent sound.

To illustrate the relationship of defect to product recovery, we will compare scalers' estimates of sound log volumes to actual change in product recovery. There should be a relationship between the predicted soundness of logs and how much lumber is actually recovered.

Product recovery used for this comparison is cubic recovery percent calculated as (cubic volume of lumber/gross cubic volume of log)(100).

Table 3 shows the cubic recovery percents and the percent sound for the four classes of logs. It is apparent in table 3 that product recovery decreases from live logs through the classes. Estimated percent sound also decreases within each scaling system. Whether these estimates of soundness correspond to actual changes in volumes of products is not apparent.

The relationship between actual change in product recovery relative to the change in percent sound is shown in table 4. An explanation of how these changes are calculated is shown in the footnotes of table 4.

Table 3--Comparison of product recovery by deterioration class to soundness of white pine logs as estimated by 3 scaling systems

Deterioration class	Cubic recovery[1]	Estimated sound[2]		
		Net Scribner	Net cubic	Product potential cubic
	Percent			
Live	44.6	93.3	99.1	91.8
Class I	41.1	51.3	97.0	60.5
Class II	36.4	21.0	94.8	40.2
Class III	31.4	6.2	88.4	19.6

[1]Based on gross cubic volume and shown as an arithmetic average adjusted to a common diameter base between classes.

[2]The complement to the defect percent (100 minus defect percent) shown in table 2.

Table 4--Change in product recovery relative to change in soundness by deterioration class for western white pine logs

Deterioration class	Change in[1] actual volume of product	Change in estimated soundness[2]		
		Net Scribner	Net cubic	Product potential cubic
		Percent		
Live[3]	0	0	0	0
Class I	-7.8	-45.0	-2.1	-34.1
Class II	-18.4	-77.5	-4.3	-56.2
Class III	-29.6	-93.4	-10.8	-78.6

[1]Based on change in percent of gross cubic recovery from table 3. The decrease in product recovery from live to class I is calculated as (44.6-41.1/44.6)(100) = 7.8 percent.

[2]Based on change in estimate from table 3. The decrease in percent sound from live to class I for net Scribner is calculated as: (93.3 - 51.3)/(93.3)(100) = 45.0 percent.

[3]Live logs used as a base for comparison.

Table 4 shows that net Scribner and product potential overestimate the impact of defects on product volume, whereas net cubic underestimates the impact. For instance, product volume for class II logs decreased by 18.4 percent, yet estimated soundness of the same logs decreased by 77.5 percent for net Scribner and 56.2 percent for product potential. On the other hand, soundness based on net cubic decreased by 4.3 percent, indicating that the defect deduction was less than the actual change in product volume.

It is obvious that none of the systems accurately predicted the loss of product volume. We can look at the systems individually to explain why the estimates were incorrect:

Net Scribner.--The 45-percent decrease in predicted soundness from live to class I was primarily due to checking. The 7.8-percent decrease in product volume indicates that checking did not have this great an impact on lumber recovery. There was a reduction in volume because of checking, but the technique used in Scribner scale to estimate this loss results in deductions that exceed the actual loss. We encountered little spiral checking in this study; but where spiral checks occur a larger loss of lumber volume can be expected. Checking plus sap rots and weathering causes the high defect in the class II and III logs. Again, Scribner scaling techniques result in deductions that exceed actual product loss.

Net cubic.--Net cubic is intended to predict the volume of a log that is suitable to produce a solid chip. Since net cubic does not consider checks as deductions, the reduction in percent sound is less than for Scribner. Even in the class III logs, estimated soundness was only reduced by 10.8 percent. This 10.8 percent corresponds to a 29.6-percent loss in product volume. Whereas Scribner overestimates the impact of defects on product volume, net cubic underestimates the impact.

Product potential cubic.--As with Scribner, this scale reduces estimates of log volumes for defects that are supposed to reduce lumber tally volume. The large reductions in estimated percent sound in this scaling system show much the same pattern as net Scribner scale (see table 4). Even though the percent sound estimates are closer to actual product volume loss, they still exceed the actual loss. As with Scribner, this scale overestimates the impact of checks on product volume.

Table 4 shows that the most accurate estimates of percent sound relative to product volume lie between net cubic and product potential cubic. For example, the change in product volume for class I logs was a minus 7.8 percent, whereas the change in percent sound was a minus 2.1 percent for net cubic and minus 34.1 percent for product potential cubic. This relationship also holds true for the other classes. In all cases, estimates of percent soundness based on Scribner techniques were the poorest and those based on net cubic were the best.

We have confined our discussion to relating product recovery to estimates of percent sound. What if the impact of defect is disregarded? Product recovery can be based on gross estimates as well as net in either Scribner or cubic scale. If we included the gross estimates, there would be five systems of measuring volume of log input: gross and net Scribner; and gross, net, and product potential cubic. Any system used to measure volume of log input should be able to predict product volume in terms of lumber tally. An analysis of how well each system predicted lumber tally is presented in detail under "Analytical Procedures."

Our intention in this section of the paper is to illustrate the relationship of product recovery to defect and scale. We have shown how estimated defect relates to actual changes of product volume and why the estimates differ from the actual change. Since product recovery is based on the scaled volumes of logs, understanding the differences between the scaling systems allows the reader to interpret the product recovery data presented in the next section.

PRODUCT RECOVERY

Dead timber undergoes a series of physical changes that affect product recovery. One result of these changes is a loss of product volume relative to live timber; i.e., for the same volume of logs sawn, less lumber will be produced from dead logs.

The volume of products recovered in relation to log input volume is important to all mill operators. For a given size and species, cost of manufacturing logs varies little, yet product volume recovered can vary substantially. This variation in product volume recovered is accentuated when dead timber is milled.

There are a number of ways of expressing the relationship of product volume to log volume: recovery ratio (overrun), cubic recovery percent, or lumber recovery factor. These product recovery ratios are defined as:

Recovery ratio (overrun) = board feet of lumber tally per board foot of net log scale expressed as a percent. It is equal to overrun plus 100 percent. Although recovery ratio has traditionally been expressed as a percent of net Scribner scale, it can also be expressed as a percent of gross Scribner scale.

Cubic recovery percent = cubic feet of rough green lumber per cubic foot of log input. It can be expressed as a percent of the gross, net, or product potential estimates of the cubic volume of a log. Cubic recovery percent can be based on surface dried lumber as well as rough green lumber.

Lumber recovery factor = board feet of lumber tally per cubic foot of log volume. As with cubic recovery percent, log input volume can be expressed either as gross, net, or product potential estimates.

Tables 5 and 6 present estimates of product recovery as a function of various scaling systems and can be used for general comparisons. Table 5 presents the various scaling systems and table 6 shows the product recovery. A more detailed breakdown of these results, including lumber yields by diameter, deterioration class, and scaling system is presented in appendix 2, tables 14-18.

Recovery Ratio (Overrun)

The most commonly used recovery ratio in the forest products industry is overrun plus 100 percent. Recovery ratios based on net Scribner scale are shown in table 6. Logs from live trees yielded a 109-percent[6/] recovery ratio based on net scale. This compares with recovery ratios of 178, 351, and 1,010 percent for classes I, II, and III logs. The high recovery ratios for the dead logs reflect excessive deductions in the scaling system. Net Scribner requires severe deductions for checking in the logs, when, in fact, lumber is actually produced around these checks. Often arbitrary deductions must be applied by the scaler to defects that have little or no effect on product recovery.

6/ The recovery ratios presented here are based on weighted class averages rather than arithmetic averages. Reasons are detailed in table 6.

Table 5--Summary of lumber tally and log scale by deterioration class for western white pine logs

Deterioration class	Number of logs	Lumber tally		Scribner scale[1]		Cubic scale[2]		
				Gross	Net	Gross	Net	Product potential
		Board feet	Cubic feet[3]	--Board feet--		- - - - - -Cubic feet- - -		
Live	53	11,731	1,065	10,970	10,430	2,000	1,963	1,808
Class I	200	32,932	2,872	32,730	18,510	5,934	5,711	3,837
Class II	132	21,287	1,854	23,010	6,070	4,071	3,689	1,809
Class III	214	29,490	2,539	36,515	2,920	6,552	5,612	1,491
Total	599	95,440	8,330	103,225	37,930	18,557	16,975	8,945

[1]Woods-length logs as scaled by USDA Forest Service scalers applying National Forest Service Log Scaling Handbook rules as of 1974.

[2]Woods-length logs as scaled by USDA Forest Service scalers applying the proposed National Forest Service Cubic Scaling Handbook rules as of June 1974. Diameters recorded in accordance with Cubic Scaling Handbook, length recorded as actual log length to nearest 1/10 of a foot.

[3]Based on rough green dimensions of lumber.

Table 6--Summary of product recovery by deterioration class for western white pine logs[1]

Deterioration class	Recovery ratio[2]		Cubic recovery			Lumber recovery factor		
	Gross, Scribner	Net, Scribner	Gross	Net	Product potential	Gross	Net	Product potential
	- - - - - -	- - - - - -	Percent	- - - -	- - - -	Board feet per cubic foot		
Live	104	109	44.6	44.8	55.1	5.0	5.0	7.4
Class I	93	3/	41.1	42.4	3/	4.7	4.9	3/
Class II	82	3/	36.4	39.2	3/	4.2	4.5	3/
Class III	76	3/	31.4	37.1	3/	3.7	4.3	3/
Average	85	3/	36.9	40.0	3/	4.2	4.6	3/

1/Product recovery presented as arithmetic averages adjusted to a common diameter between classes.

2/Recovery ratio is equal to overrun plus 100.

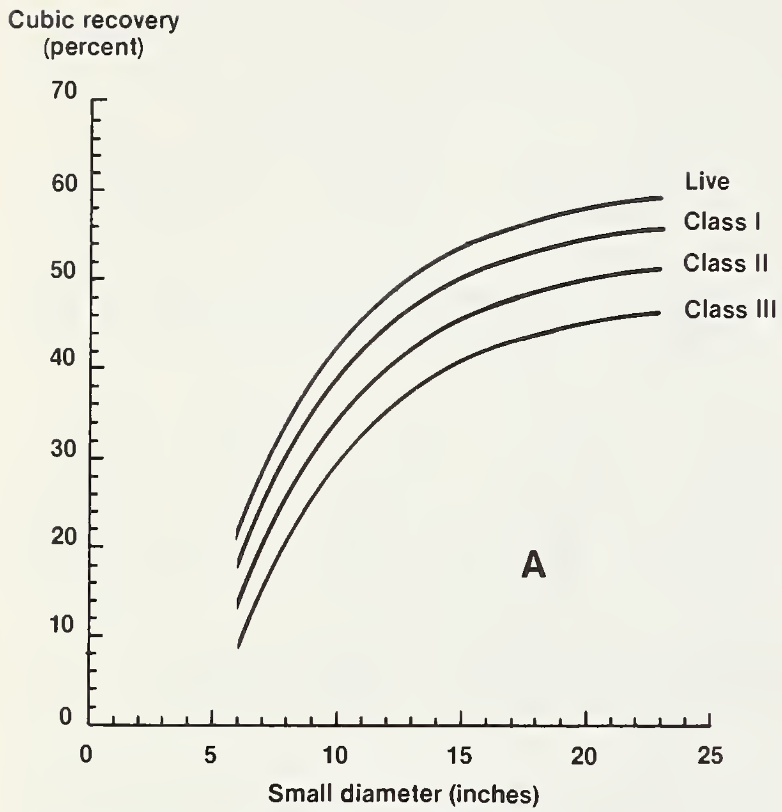
3/Not applicable; arithmetic average for the dead logs cannot be calculated because of large number of logs with zero net Scribner scale and zero product potential cubic scale. Weighted averages for net Scribner scale are: live, 112 percent; class I, 178 percent; class II, 351 percent; class III, 1,010 percent. Weighted averages for product potential cubic scale are: live, 59 percent; class I, 75 percent; class II, 102 percent; class III, 170 percent. Weighted averages for product potential lumber recovery factor are: live, 6.5 board feet/cubic foot; class I, 8.6 board feet/cubic foot; class II, 11.8 board feet/cubic foot; class III, 19.8 board feet/cubic foot.

Recovery ratio can be expressed in gross as well as net Scribner scale (table 6). When recovery ratio was based on gross Scribner, the percents decreased from 104 for the live to 76 for the class III logs. Recovery ratios based on gross Scribner are seldom used, even though this is a more realistic picture of what happens to product recovery.

Cubic Recovery

Cubic recovery percent is the proportion of the log recovered as lumber. It can be expressed as a percent of the gross, net, or product potential estimates of the cubic volume of a log.

Figure 6 shows the relationship of cubic recovery percent to log diameter for both gross and net cubic scales by deterioration class. Table 6 shows cubic recovery percent averages by class. The percent of a log converted to lumber decreases as time since death increases.



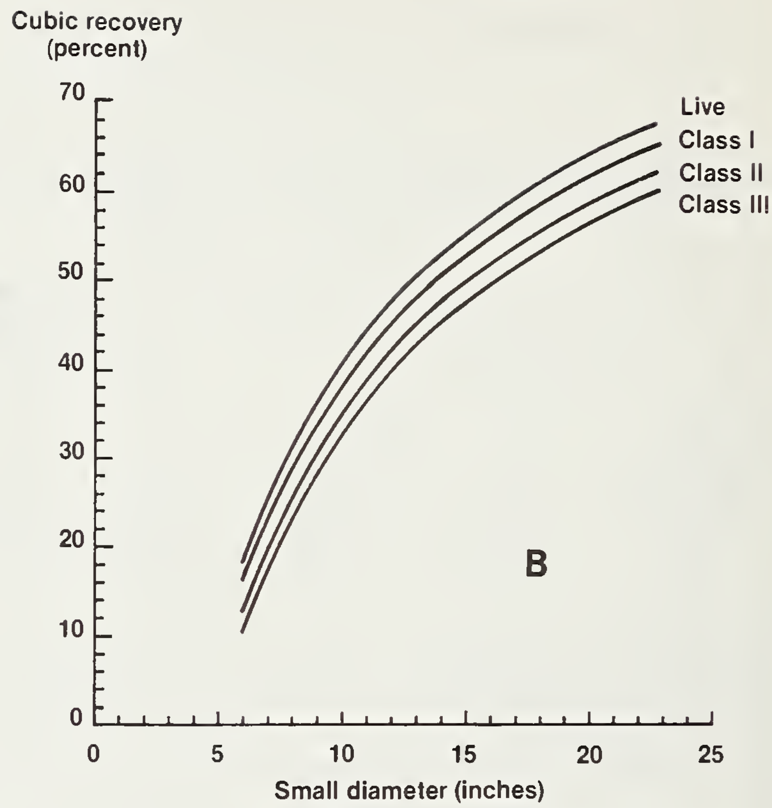


Figure 6.--Percent of cubic log volume produced as rough green lumber by log diameter and deterioration class, western white pine:

A, gross volume; statistical information--

$\hat{y}$(live)=100.24-0.71994(D)-593.18(1/D)+865.77($1/D^2$),

$\hat{y}$(class I)=96.62-0.71994(D)-593.18(1/D)+865.77($1/D^2$),

$\hat{y}$(class II)=91.99-0.71994(D)-593.18(1/D)+865.77($1/D^2$), and

$\hat{y}$(class III)=87.09-0.71994(D)-593.18(1/D)+865.77($1/D^2$).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 12.57 and 0.482.

B, net volume; statistical information--

$\hat{y}$(live)=83.80+0.29235(D)-546.02(1/D)+854.69($1/D^2$),

$\hat{y}$(class I)=81.45+0.29235(D)-546.02(1/D)+854.69($1/D^2$),

$\hat{y}$(class II)=78.20+0.29235(D)-546.02(1/D)+854.69($1/D^2$), and

$\hat{y}$(class III)=76.11+0.29235(D)-546.02($1/D^2$)+854.69($1/D^2$).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 13.87 and 0.484.

There were highly significant differences in intercepts between deterioration classes, but differences between slopes were not significant.[7] Notice that separation between classes was reduced when net cubic scale was used as the basis for measuring volume of log input.

[7]Throughout this paper, highly significant implies the 0.01 level of probability; significant, the 0.05 level.

In recently killed trees (class I), drying checks were the primary cause of the reduction in lumber volume. The stress caused by drying appeared most often to be released in one primary check, but frequently one or two smaller checks also occurred. Spiral checks were not prevalent in the study; but when they occurred, the losses of lumber volume were greater. The impact of drying checks on lumber yield is also illustrated and

discussed in the section "Lumber Dimensions." Additional losses in the older dead material were due mainly to weathering, sap rots, and borers. Figures 1-5 illustrate these losses.

The cubic volume of all components of a log can be delineated and expressed as a percent of the total log volume (fig.7). The rough green cubic recovery is indicative of the lumber volume a log is capable of producing. The surface dry cubic recovery is the same lumber as the rough green minus the loss from shrinkage and surfacing. The relationship between rough green cubic and surface dry is an indication of a mill's efficiency. For example, 41.1 percent of the log volume in class I was converted to rough green lumber, and 27.4 percent was ultimately produced as surface dry lumber. Thus, about 67 percent (27.4/41.1 = 66.6) of the rough green lumber ended up as surface dry lumber. This relationship will be reasonably constant for all classes. Fahey and Woodfin (1976) and Dobie and Wright (1970) give detailed explanations of these relationships.

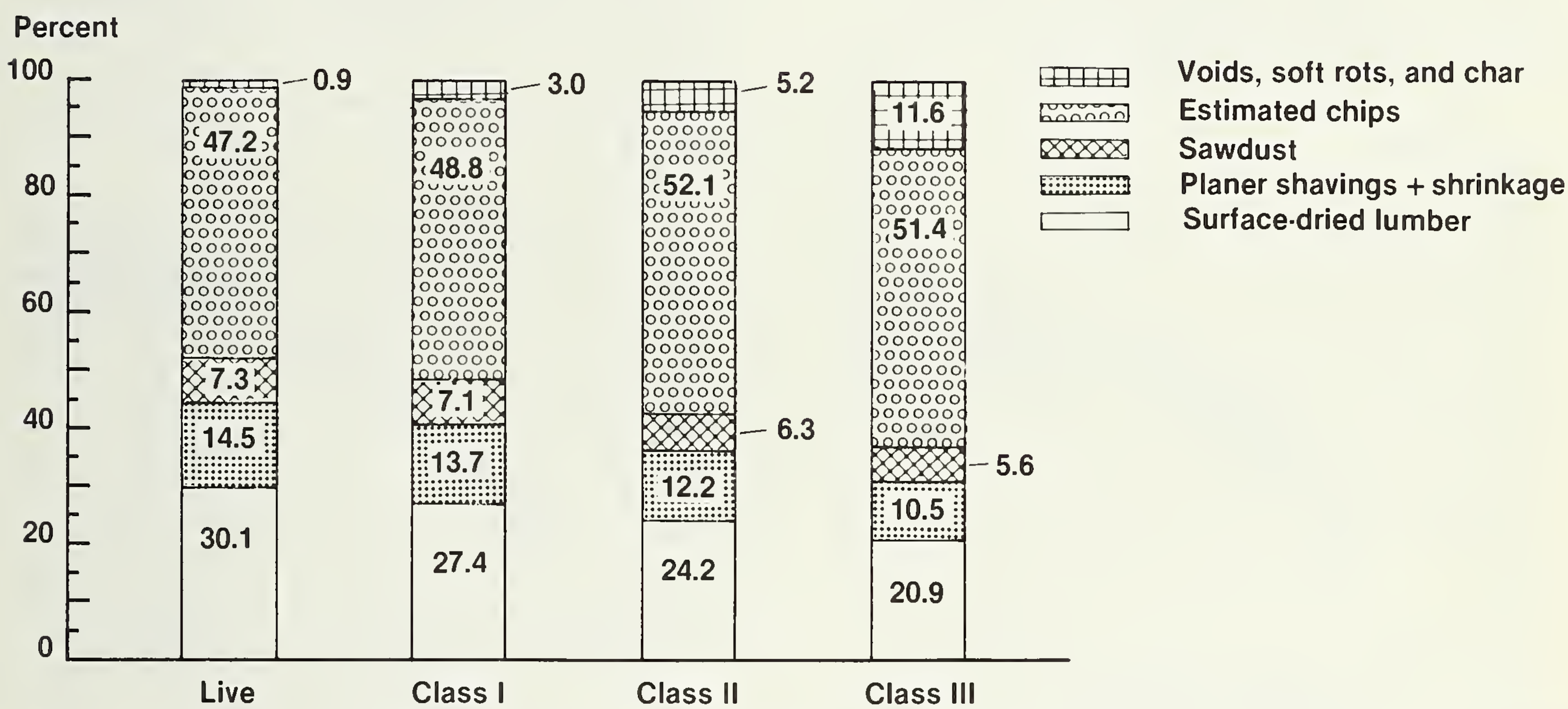


Figure 7.--Cubic volume of log components expressed as a percent of total gross log cubic volume by deterioration class, western white pine. Note that surfaced dried lumber plus planer shavings and shrinkage equal rough green lumber.

After the lumber is removed, the remaining volume of the log can be separated into sawdust volume, chippable volume, and voids. Sawdust and chippable volumes are calculated; voids are the difference between gross cubic and net cubic scale.

Lumber Recovery Factor (LRF)

Lumber recovery factor is board feet of lumber tally per cubic foot of log volume. As with cubic recovery, an LRF estimate can be based on either gross cubic, net cubic, or product potential estimates. LRF and cubic recovery percent are nearly identical estimates of product volume; the difference is that lumber output is measured in board feet in LRF and in cubic feet in cubic recovery percent. There are minor differences between the two as the actual lumber size varies by dimension.

Average LRF's for the various deterioration classes of logs are shown in table 6. The curved relationship of LRF over log diameter is shown in figure 8. The curves follow the same patterns as those for cubic recovery in figure 6. As with the cubic recovery curves, there were highly significant differences between class intercepts and no significant difference between slopes. Explanation of differences in product recovery between live and dead logs in terms of LRF is the same as for cubic recovery.

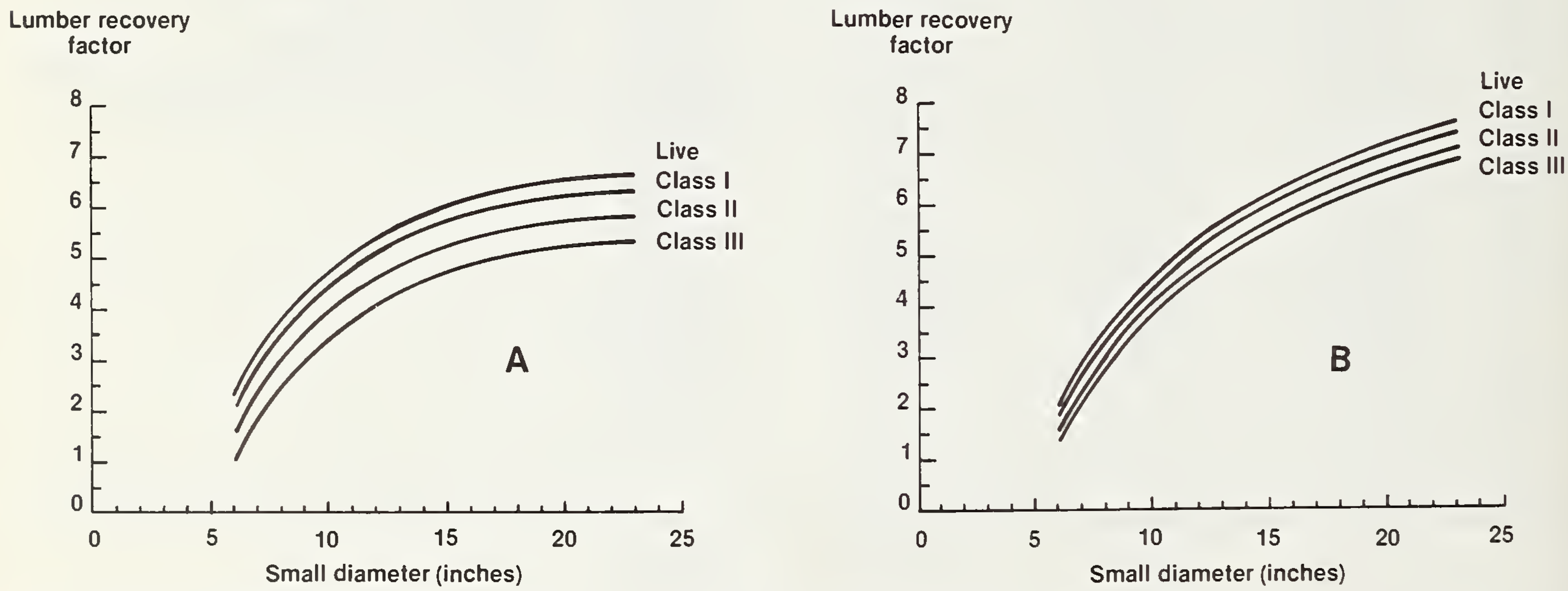


Figure 8.--Lumber recovery factor: Board-foot lumber tally per cubic foot of log by diameter, western white pine.

A, gross volume; statistical information--

$\hat{y}(\text{live})=11.38-0.0861(D)-67.69(1/D)+98.72(1/D^2)$,

$\hat{y}(\text{class I})=11.09-0.0861(D)-67.69(1/D)+98.72(1/D^2)$,

$\hat{y}(\text{class II})=10.60-0.0861(D)-67.69(1/D)+98.72(1/D^2)$, and

$\hat{y}(\text{class III})=10.06-0.0861(D)-67.69(1/D)+98.72(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 1.40 and 0.482.

B, net volume; statistical information--

$\hat{y}(\text{live})=9.53+0.0290(D)-62.67(1/D)+98.57(1/D^2)$,

$\hat{y}(\text{class I})=9.39+0.0290(D)-62.67(1/D)+98.57(1/D^2)$,

$\hat{y}(\text{class II})=9.59+0.0290(D)-62.67(1/D)+98.57(1/D^2)$, and

$\hat{y}(\text{class III})=8.85+0.0290(D)-62.67(1/D)+98.57(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 1.56 and 0.504.

Chip and Sawdust Recovery

Even though markets for chips are undependable, chip yields are necessary to determine the total value of logs. Sawdust is a residue generally used as hogged fuel; but with the cost of energy, this product is becoming more important.

Volumes of chips are determined by subtracting the rough green cubic volume of lumber and calculated volume of sawdust from the gross volume of logs. Any defect for voids, soft rots, and char (i.e., net cubic deductions) are also removed from the gross volume. Sawdust volumes are based on average saw kerf and the number and sizes of boards produced. Appendix 1 documents the procedures used in determining yields from chips and sawdust.

The trend of chip and sawdust yields expressed as a percent of the volume of logs is shown in figure 7. Because the percent of the log produced as rough-green lumber decreased as time since death increased, we assumed that the percent of chips would increase. Chip yields were about 47 percent for live logs; 49 percent for class I; 52 percent for class II; and 51 percent for class III. The decrease in class III log volume recovered as chips is probably due to loss from voids, soft rots, and char (fig.7). The impact of the voids, soft rots, and char is also reflected in class I and II logs. The increase in chip yields for those logs was not as high as expected, considering the decrease in lumber output.

Chip yields were converted from volume to weight since values are generally expressed in dollars per bone dry unit.[8/] The average pounds of chips per gross and net cubic foot of log input are shown in the following tabulation:[9/]

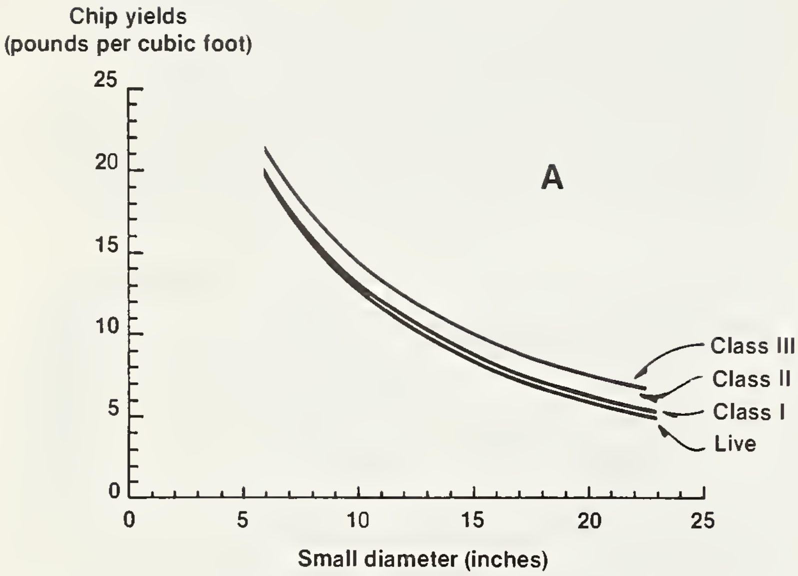
Deterioration class	Cubic log scale: Gross	Net
	(pounds/cubic foot)	
Live	11.6	11.7
I	11.8	12.2
II	13.2	13.8
III	13.2	14.6

These averages will give a general idea of the relationship between classes. The effect of diameter on chip yields, however, was so important that we suggest the curves shown in figure 9 be used.

Figure 9 shows the relationship of chip yield to log diameter. The higher yields in the smaller diameter logs were expected since chip yields are strongly affected by lumber yields. The curves for chips are the complement to the cubic lumber recovery curves; e.g., smaller logs produced less lumber, thus more chips per unit of log volume. The effect of producing a higher percentage of the volume of small logs in slabs and edgings results in these curve shapes.

[8/] A bone-dry unit is a quantity of wood residue that would weigh 2,400 pounds at 0-percent moisture content.

[9/] Average as used here is an arithmetic average adjusted to equalize diameter differences between classes.



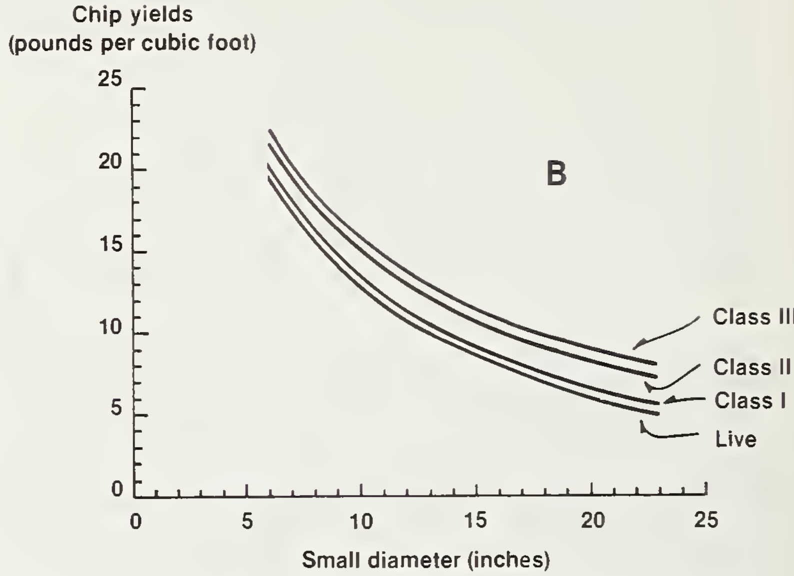


Figure 9.--Yields of ovendry chips per cubic foot of log input over diameter, western white pine:

A, gross volume; statistical information--

$\hat{y}(\text{live})=-2.98+0.008(D)+189.0(1/D)-326.0(1/D^2)$,

$\hat{y}(\text{class I})=-2.69+0.008(D)+189.0(1/D)-326.0(1/D^2)$,

$\hat{y}(\text{class II})=-1.29+0.008(D)+189.0(1/D)-326.0(1/D^2)$, and

$\hat{y}(\text{class III})=-1.33+0.008(D)+189.0(1/D)-326.0(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 3.87 and 0.533.

B, net volume; statistical information--

$\hat{y}(\text{live})=-2.26+0.002(D)+180.0(1/D)-301.0(1/D^2)$,

$\hat{y}(\text{class I})=-1.71+0.002(D)+180.0(1/D)-301.0(1/D^2)$,

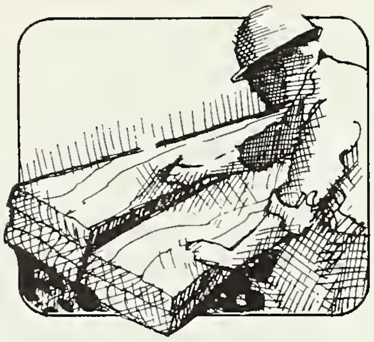
$\hat{y}(\text{class II})=-0.13+0.002(D)+180.0(1/D)-301.0(1/D^2)$, and

$\hat{y}(\text{class III})=0.64+0.002(D)+180.0(1/D)-301.0(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 3.91 and 0.529.

Covariance analysis indicated a highly significant difference between the classes, yet in reality the advantage gained in explained variation, by separating into classes, was small. Expressed as pounds of chips per gross cubic-foot input (fig.9A), the difference was primarily between two groups represented by live logs plus class I, and class II plus class III logs. Expressed as a percent of net cubic-foot input (fig. 9B), the differences between classes were more uniformly distributed. The impact that chip yields have on log values is shown in the section, "Log Value."

Sawdust yields expressed as a percent of log input volume are shown in figure 7. Sawdust yields were 7.3, 7.1, 6.3, and 5.6 percent of log volume for live through class III logs. The average was about 2 pounds of sawdust per gross or net cubic foot of log input for all classes combined.



LUMBER YIELDS

In addition to changes in volumes of products recovered from dead timber, product quality (grade) changed even more drastically. Changes occurred in lumber dimensions as well as in lumber quality. These changes in grade and dimension determine lumber value. Differences in average values of lumber are tested in the lumber value section.

Lumber Grade Yields

A comparison of the percentages[10] of lumber grades by grade groupings emphasizes another difference between live and dead timber (fig. 10). A pattern emerges in which the live trees produce a high percentage in No. 2 Common and Better (the higher grades), and the oldest dead trees produce a high percentage in No. 4 and 5 Common. Even in the oldest dead categories there was more No. 3 Common and Better than No. 5 Common. The white pine lumber grade yields from green logs in this study are similar to the yields for the live grade 4 logs in a previous study by Plank and Snellgrove (1973).

10/ Average percent as used here is a weighted average of each lumber grade by class.

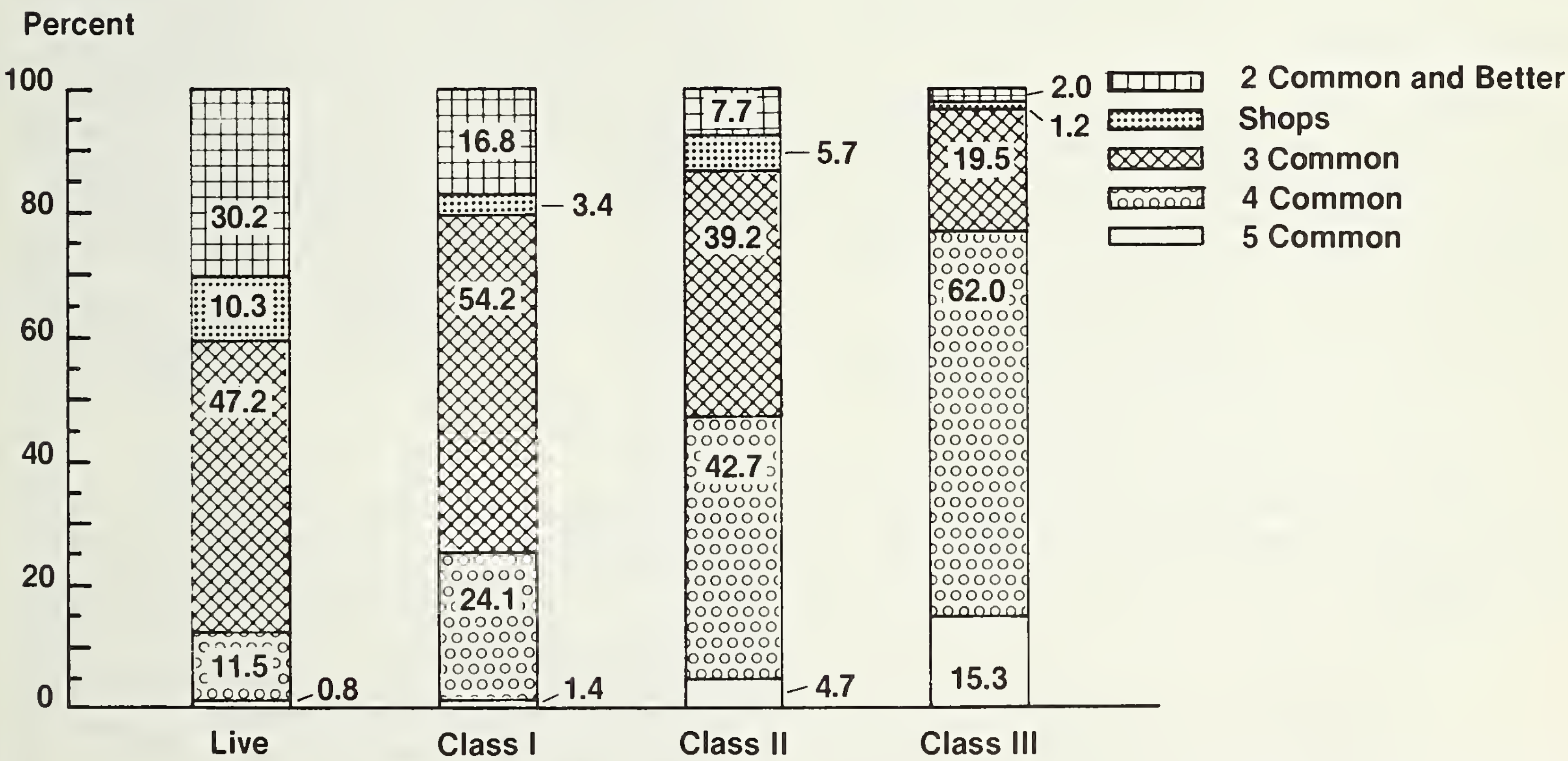


Figure 10.--Lumber grade yield as a percent of total lumber tally volume by deterioration class, western white pine.

Initially, lumber degrade was caused by blue stain and splits due to drying checks. Blue stain dropped lumber from the Shop grades as well as from No. 2 Common and Better down to No. 3 Common. This degrade does not occur in material that produces primarily dimension items. In dimension lumber, items are graded on strength rather than appearance, and stain is not a factor in degrade. Splits caused by drying checks contributed more to loss of volume than to degrade. They generally resulted in narrow boards due to more edging.

Wormholes were present but not prevalent in the dead logs. Even when present, they did not significantly limit lumber grade since they were generally confined to the base of the oldest dead trees. The majority of lumber from the oldest dead trees had already been degraded to No. 3 or 4 Common, and these grades allow some holes. As with splits, sap rots contributed more to loss of lumber volume than to degrade.

When lumber grade yields from dead timber are evaluated, there is another important point to consider--grade loss will be greatest in the highest quality logs. No attempt was made to sample the truly high quality white pine (large diameter, limb-free trees) in this study. It is a relatively minor component of the resource base and will continue to decrease as a percent of the overall resource. Since this high grade material produces a high percentage of Shops and Selects, the impact of stain degrading the lumber to No. 3 Common assumes even greater importance.

Lumber Dimensions

Most board items are priced by dimension as well as by grade. Consequently, lumber width will have an impact on the value of the final product. The impact of drying checks on width is illustrated in table 7. The percentage of narrow lumber, 6 inches and narrower, increased from 20 percent to 35 percent for the live to class III group. Conversely, the percentage of wide lumber (1 by 10's and 1 by 12's) decreased from live to class III. A complete breakdown of lumber yields by dimension and grade is presented in appendix 2, tables 19-23.

There can be a twofold impact from more narrow lumber being produced in dead material: (1) narrow boards are generally worth less; and (2) a large influx of narrow boards, particularly in the lower grades of lumber, could adversely affect marketability of the material.

Table 7--Percentage of western white pine lumber by width and deterioration class

Width	Deterioration class			
	Live	I	II	III
	Percent			
6 inches and narrower[1]	20	24	27	35
8 inches	16	18	18	15
10 inches and wider[2]	64	58	55	50
Total	100	100	100	100

[1] Includes 4- and 6-inch lumber.

[2] Includes 10-inch and 12-inch lumber.

From our observation, the impact of checking is considerably greater when more than one check occurs or when spiral checks are involved. The impact of checking on volume and value is also affected by the type of lumber produced. It is most severe in Board and Shop items where all widths are produced and where wide boards are worth more. The impact on dimension lumber is less because many mills produce primarily narrow widths. Another generalization can be made--the thicker the item produced, the less impact checking will have. A timber, for instance, is more apt to remain intact and retain a higher grade than a board.

Lumber Value Loss

As shown in figure 10 and table 7, lumber grade yields and dimensions varied substantially by deterioration class. The impact of this variation can best be expressed in dollars per thousand board feet of lumber tally ($/MLT) and is shown in the following tabulation:

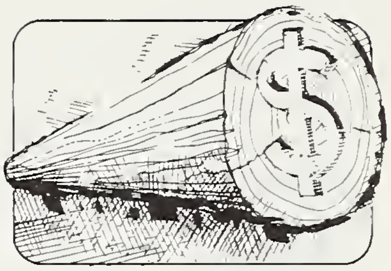
Deterioration class	Average board value $/MLT	99-percent confidence interval
Live	204.00	±16.00
Class I	160.00	±7.00
Class II	122.00	±7.00
Class III	101.33	±4.00

Dollars per thousand lumber tally is the average value (based on an arithmetic average) of the lumber produced. It does not include the loss of volume. The average value of the lumber decreased from live through the three deterioration classes.

In this study there is virtually no relationship between $/MLT and log diameter. Yet, there is a significant difference in average $/MLT between classes. Variation accounted for in regressing over log diameter was less than 2 percent. On the other hand, about 52 percent of the total variation was accounted for by stratifying the logs in classes. Consequently, we suggest using class averages when estimating lumber values.

The value of the lumber produced varies as lumber price varies. Tables 19-23, which are the percent of total lumber production by grade and dimension, are presented in appendix 2. This information is included to allow the user to apply current prices to the data.

LOG VALUE



We have described the losses from lumber volume and from lumber value; we now need a composite figure to reflect both these losses in logs. Table 8 shows changes in lumber volume and value and several ways of expressing the dollar values. The dollar values depend on how the log volumes are estimated.

In this table, differences in lumber volume are shown in terms of cubic recovery, and differences in lumber value are shown in dollars per thousand board feet lumber tally. Excessive deductions made in net Scribner scale and in cubic product potential scale are reflected by the artificial increase in value of older dead material (see footnotes 2 and 3 of table 8). Values per unit of volume increased as time since death increased--a contradiction to how a scaling and grading system should perform. Log values expressed as dollars per hundred cubic feet gross or net ($/CCF) scale and dollars per thousand board feet gross Scribner scale all decreased as time since death increased.

Figure 11 shows the relationship of $/CCF of gross and net scale over log diameter.[11/] The solid lines include the combined value of lumber and chips, whereas the dotted lines represent only lumber. The most important aspect of adding chip values relates to the value of the marginal log. When chips can be marketed they may be the difference between a log's being profitable or unprofitable.

Figure 12 is the same as figure 11A but shows combined lumber and chip values only. It illustrates how figure 11 might be used.

Assuming a fixed production cost (logging and milling) of $70/CCF, we see how much dollar surplus is available for stumpage and profit and risk. A buyer might only be able to allow $17/CCF for stumpage and profit and risk for class II logs in the 19-inch diameter class. On the other hand, about $67 could be allowed for the live logs in the 19-inch diameter class. These values represent the difference between the production cost line and the total value curves for each deterioration class. Only the 19-inch and larger class III logs would exceed production costs, whereas 12-inch class II, 8-inch class I, and 5-inch live logs would all exceed these hypothetical costs. If the value of chips were removed (as shown in fig. 11), a larger log would be needed to realize a profit.

[11/] Comparison of deterioration classes in figure 11 shows a highly significant difference in slopes and intercepts for the curves. The difference in slope was not considered a practical difference even though it was statistically significant; consequently, a common slope was used for both gross and net figures.

Table 8--Average losses of lumber volume and value and log values by scaling system and deterioration class[1/]

Deterioration class	Cubic recovery	Lumber value	Log values by scaling system: Scribner scale — Gross	Scribner scale — Net	Cubic scale — Gross	Cubic scale — Net	Cubic scale — Product potential
	Percent	Dollars/thousand board feet			Dollars/hundred cubic feet		
Live	44.6	204.13	212.87	2/	103.45	103.88	107.49
Class I	41.1	160.33	149.16	2/	76.12	78.68	3/
Class II	36.4	122.49	101.00	2/	52.54	56.61	3/
Class III	31.4	101.33	77.18	2/	37.47	43.66	3/

1/All averages except dollars per thousand board feet net log scale and dollars per hundred cubic feet product potential are arithmetic averages adjusted to a common diameter base between classes.

2/Not applicable; arithmetic averages cannot be calculated for the dead logs because of the large number of logs with zero net Scribner scale and zero product potential cubic scale. Weighted averages for net scale are: \$240.69, \$299.19, \$484.93, and \$1,043.38 for live logs and classes I, II, and III logs.

3/Weighted averages for product potential are \$107.49, \$230.39, \$475.97, and \$1,295.11 for live logs and classes I, II, and III logs.

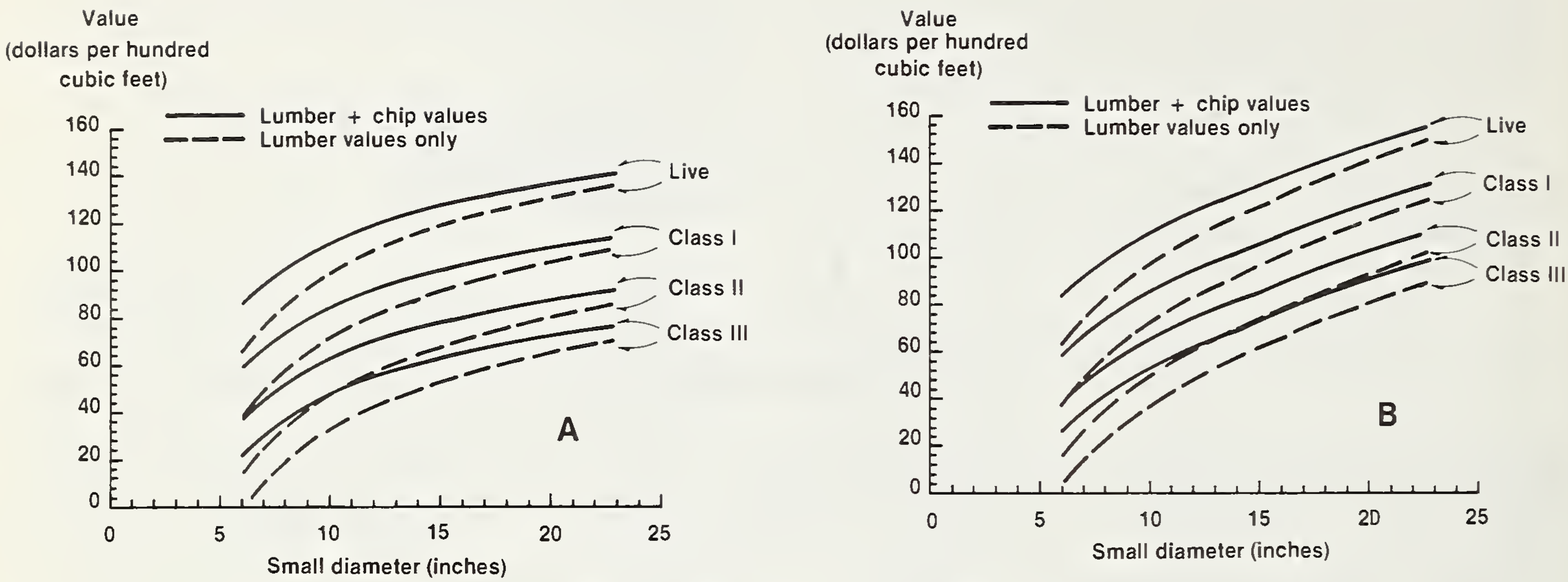


Figure 11.--Values per hundred cubic feet of log volume by diameter and deterioration class, western white pine:

A, gross values; statistical information--

Lumber plus chips:

$\hat{y}$(live)=150.23+0.5034(D)-493.22(1/D)+531.7(1/D^2),

$\hat{y}$(class I)=123.20+0.5034(D)-493.22(1/D)+531.7(1/D^2),

$\hat{y}$(class II)=101.08+0.5034(D)-493.22(1/D)+531.7(1/D^2), and

$\hat{y}$(class III)=85.98+0.5034(D)-493.22(1/D)+531.7(1/D^2).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 22.61 and 0.559.

Lumber values only:

$\hat{y}$(live)=153.34+0.4948(D)-690.11(1/D)+871.1(1/D^2),

$\hat{y}$(class I)=126.07+0.4948(D)-690.11(1/D)+871.1(1/D^2),

$\hat{y}$(class II)=102.42+0.4948(D)-690.11(1/D)+871.1(1/D^2), and

$\hat{y}$(class III)=87.36+0.4948(D)-690.11(1/D)+871.1(1/D^2).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 24.38 and 0.580.

B, net values; statistical information--

Lumber plus chips:

$\hat{y}$(live)=103.17+2.6889(D)-194.47(1/D)-159.0(1/D^2),

$\hat{y}$(class I)=78.58+2.6889(D)-194.47(1/D)-159.0(1/D^2),

$\hat{y}$(class II)=58.28+2.6889(D)-194.47(1/D)-159.0(1/D^2), and

$\hat{y}$(class III)=45.99+2.6889(D)-194.47(1/D)-159.0(1/D^2).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 22.30 and 0.579.

Lumber values only:

$\hat{y}$(live)=112.06+2.47(D)-442.65(1/D)+327.7(1/D^2),

$\hat{y}$(class I)=86.85+2.47(D)-442.65(1/D)+327.7(1/D^2),

$\hat{y}$(class II)=64.78+2.47(D)-442.65(1/D)+327.7(1/D^2), and

$\hat{y}$(class III)=51.83+2.47(D)-442.65(1/D)+327.7(1/D^2).

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but indivudual class intercepts are, respectively, 25.10 and 0.587.

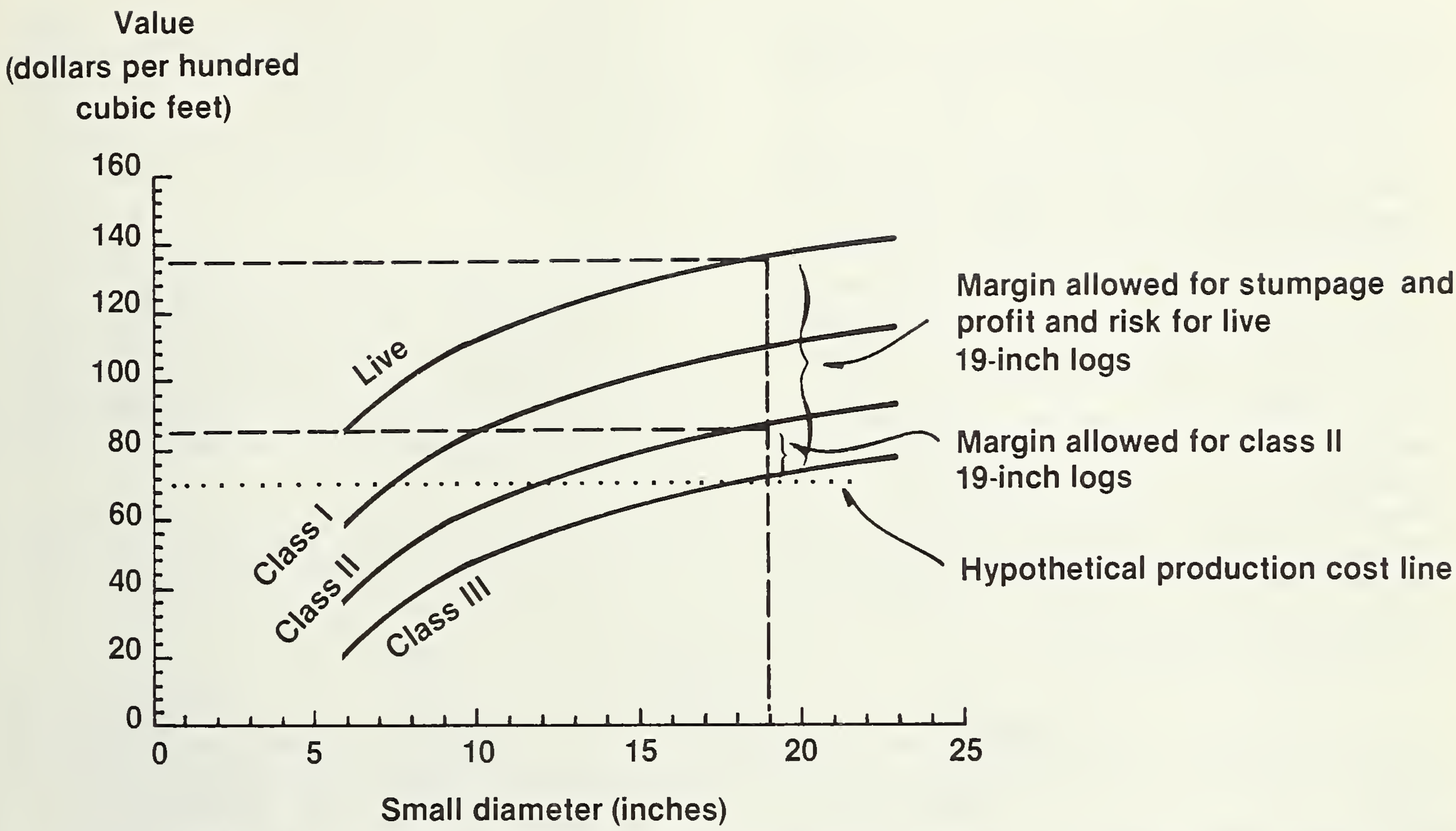


Figure 12.--Values per hundred cubic feet of gross log volume by diameter and deterioration class, western white pine. Includes hypothetical production cost line. These curves are the same as figure 11A curves for lumber plus chip values.

Table 9 shows values retained for logs with and without chip values by gross and net cubic scaling systems. Table 9 indicates that expressing values on a net cubic scale basis reduces the difference between classes. For example, there is a 64-percent difference (100-36) between live and class III logs based on gross cubic scale, whereas there is a 58-percent difference between the same classes based on net cubic scale. Using lumber plus chip values, rather than lumber value alone, further reduces the difference between classes. Lumber plus chip values based on net cubic scale showed a 49-percent difference. Differences between classes are reduced with net scale because defective portions of logs that will not yield solid wood products are recognized and deducted.

Table 9--Values retained expressed as a percent of live log value, western white pine[1/]

Deterioration class	Lumber values		Lumber plus chip values	
	Gross cubic scale	Net cubic scale	Gross cubic scale	Net cubic scale
	Percent			
Live	100	100	100	100
Class I	74	76	77	79
Class II	51	54	57	61
Class III	36	42	44	51

[1/]Values used to derive the percents are arithmetic averages adjusted to a common diameter. The values are dollars per hundred cubic feet of gross and net cubic scale.

Another way of looking at loss in total value is to apportion it to volume and grade losses. Table 10 shows the average values of logs expressed in $/CCF of gross log input. It also shows the dollar loss by class and percent loss to volume and grade.

Initially there is a large loss in lumber grade. About two-thirds of the loss in class I and II logs was due to grade. Volume losses became more important in the older dead material because there is less grade to lose in this category.

Table 10--Average log value by deterioration class and value lost by volume and lumber grade, western white pine

Deterioration class	Average log value[1]	Total dollar loss[2]	Loss of log value by:[3]			
			Volume		Grade	
	$CCF[4]	$CCF[4]	$CCF[4]	Percent	$CCF[4]	Percent
Live	103.45	0	0	0	0	0
Class I	76.12	27.33	8.07	29.5	19.26	70.5
Class II	53.54	50.91	19.03	37.4	31.88	62.6
Class III	37.47	65.98	30.62	46.4	35.36	53.6

1/Value is shown as arithmetic averages adjusted to a common diameter between classes.

2/Live logs are the base.

3/Volume loss is represented by cubic recovery percent based on gross cubic scale; value loss is represented by the average value of lumber.

4/$/CCF is dollars per hundred cubic feet of gross log scale.

Tree Information

Even though most financial transactions in the forest products industry are carried out in log units, information on trees also serves an important function. For the land manager, the tree is the basic unit for inventorying lands, cruising sales, and determining expected residues for fire management. The forest products industry check-cruises trees, develops logging plans, and evaluates stand components in the form of trees. As researchers, we generally start product recovery studies with trees. Sampling begins with trees, and the ultimate effect of deterioration must be explained in trees. Breakage, for instance, is best described in trees.

Tree volumes can be separated into individual components pertaining to their utilization. These volumes expressed as a percent of tree volume to a 6-inch top are shown in table 11.

Volumes of long butts, breaks after felling, and missing pieces occur on an irregular basis between classes; volumes of long butts and of missing pieces should occur on an irregular basis, but we expected breaks after felling to increase with time since death. This did not happen, but the volumes involved were so small that the results do not necessarily indicate what would happen with a larger sample. Volumes of saw logs showed the pattern we expected through class II. Class III volumes showed a slight increase, but this was due to the random pattern in volumes of long butts, breaks after felling, and missing pieces.

The top volumes (the volume of the tree from height at 6 inches to total height) are not shown in table 11 but were a constant 2 percent between classes when expressed as a percent of total tree volume.

Deterioration after a tree's death results in three losses: (1) logging and handling losses in the woods and mill yard, (2) losses of lumber volume, and (3) lumber degrade.

With the exception of logging and handling losses, all other effects of deterioration have been discussed in terms of logs. This section is directed toward presenting results, rather than interpreting the data since the data were interpreted in the log section. This section primarily addresses logging and handling losses, losses of lumber volume, and average losses of lumber value ($/MLT), which ultimately lead to total dollar loss for the tree.

Table 11--Individual components of volume expressed as a percent of total cubic volume to a 6-inch top, western white pine trees[1/]

Deterioration class	Volume to 6-inch top[2/]	Saw log	Long butt	Felling breaks	Breaks after felling	Missing pieces	No recovery	Total
	Cubic feet				Percent[3/]			
Live	2,217	88.4	6.5	3.5	0	1.0	0.6	100
Class I	6,759	86.5	5.1	4.3	0.3	2.5	1.3	100
Class II	4,901	80.9	7.4	6.8	.9	1.9	2.1	100
Class III	7,720	81.2	6.5	7.6	.3	1.6	2.8	100

1/Saw-log is the log portion of the tree from which some lumber was recovered. Long butt is the portion of the tree bucked at the time of felling and left onsite because of defect. Felling breaks is the portion of the tree identified as breakage caused by the felling operation. Breaks after felling is the portion of the tree identified as breakage subsequent to felling and prior to sawing. Missing pieces is the portion of the tree not accounted for. No recovery is the log portion of the tree that was sawn but from which no lumber was recovered.

2/Calculated from the stump height to a 6-inch top. Smalian's formula used for all portions of tree other than butt log. Bruce's equation for cubic volume applied to butt logs.

3/Weighted average of each deterioration class.

LOGGING AND HANDLING LOSSES

A summary of logging and handling losses expressed as a percentage of the tree volume to a 6-inch top is shown below:

Deterioration class	Breakage (Percent)
Live	3.5
I	4.6
II	7.7
III	7.9

This tabulation shows the combined effect of all breakage from table 11.

All losses of tree volume are based on the cubic-foot volume of the tree to a 6-inch top. The losses resulted from felling breaks and breaks after felling. Felling breaks accounted for the majority of the volume loss in all classes. Other breakage was caused by skidding, handling in the woods and the mill yard, and handling at the debarker. This breakage accounted for less than 1 percent of the total in each class. Breakage increased from live through the classes, but the increase was minimal between class II and III. This is a logical pattern in that wood becomes more brash as it dries. At a point somewhere between class II and III. the stem of the tree has probably reached equilibrium moisture content;[12] thus breakage does not change substantially.

[12] Equilibrium moisture content is the moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

The percentages for breakage shown here do not necessarily indicate breakage that would occur in other situations. The trend of increased breakage is more important than the specific rates. Breakage from felling will vary with height of tree, percentage of tree in crown, steepness and ruggedness of terrain, basal area per acre, logging method, and inherent defect. Breakage after felling will vary according to all these factors plus type of logging and debarking equipment. In this study terrain varied from moderately steep to flat. Logs were skidded by rubber-tired skidder and crawler tractor.

This increased breakage presents problems beyond the loss of volume. Virtually all mills have preferred lengths of logs for handling and processing. In this study, the preferred length for short logs was 16 feet plus trim (roughly 17 feet). The following tabulation shows the percentage of log volume that was in 16-foot lengths.

Deterioration class	Percent of log volume in 16-foot lengths
Live	80.1
I	74.3
II	71.2
III	73.3

The trends in percent of volume in 16-foot lengths is emphasized rather than actual differences between classes. The trend shows the same pattern as breakage, in that live trees produced the highest percentage of volume in 16-foot lengths (80.1 percent). The percent decreased, as was expected, in class I and class II. Even though the percent of volume in 16-foot logs increased from class II (71.2 percent) to class III (73.3 percent), this is consistent with breakage shown in the previous tabulation. The reason for this apparent anomaly relates to the dead trees reaching equilibrium moisture content somewhere between class II and class III.

In a mill that produces items of random lengths, the percent of volume in off-length logs may not be a severe problem; however, in a mill where specified lengths are required, such as a stud mill, additional losses of volume occur, and this could have a major impact on production costs as well as values obtained.

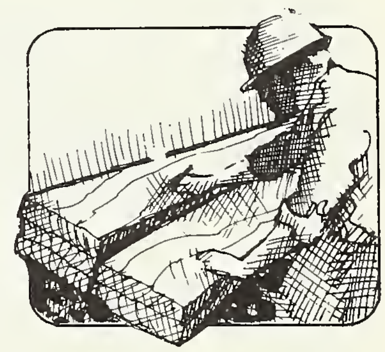
PRODUCT RECOVERY

Product recovery in trees is represented by cubic recovery percent. It is the same as cubic recovery of logs but is expressed as a percent of tree volume to a 6-inch top. Average cubic recovery based on gross log scale for live logs, and classes I, II, and III were 42.5, 39.7, 34.7, and 30.2 percent, respectively.[13] Appendix III, tables 24-28, presents a detailed breakdown of lumber yields by tree diameter, deterioration class, and scaling system.

Figure 13 presents the relationship of cubic recovery to tree d.b.h. As with the cubic recovery percent curves for logs, there were highly significant differences between class intercepts and no significant difference between slopes. The curve for tree cubic recovery is the same basic shape as for logs but more gradual. This is primarily due to the averaging effect of small logs on large trees. As with logs, the difference is reduced between classes when net cubic recovery percent is used.

[13] Average as used here is an arithmetic average adjusted to equalize diameter differences between classes.

Variables included in tree volumes but not included in log volumes include volumes lost to breakage, missing pieces, and long butts. Except for these additional variables, explanation of lumber volume loss in trees is the same as for logs.



LUMBER GRADE YIELDS

The lumber grade yields from trees is identical to yields from logs, and there is no need to duplicate the data. Figure 10 shows these lumber grade yields.

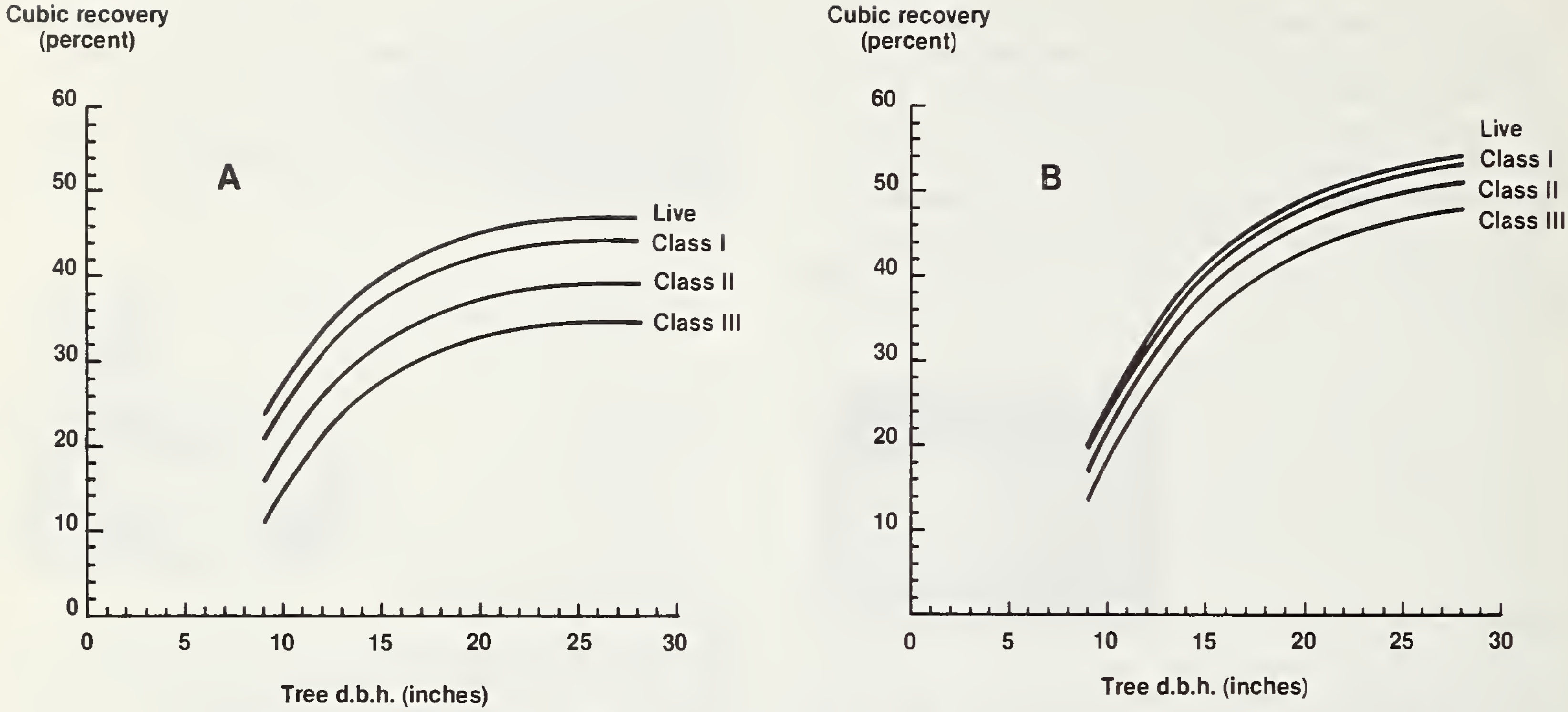


Figure 13.--Percent of cubic tree volume produced as rough green lumber by tree d.b.h. and deterioration class, western white pine:

A, gross volume; statistical information--

$\hat{y}(\text{live})=100.24-0.9540(D)-804.29(1/D)+1701.7(1/D^2)$,

$\hat{y}(\text{class I})=97.47-0.9540(D)-804.29(1/D)+1701.7(1/D^2)$,

$\hat{y}(\text{class II})=92.46-0.9540(D)-804.29(1/D)+1701.7(1/D^2)$, and

$\hat{y}(\text{class III})=87.94-0.9540(D)-804.29(1/D)+1701.7(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 8.03 and 0.503.

B, net volume; statistical information--

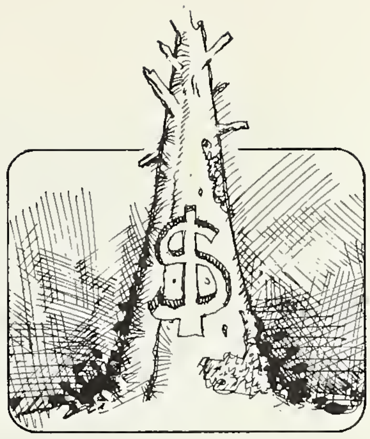
$\hat{y}(\text{live})=111.32-0.8473(D)-1021.44(1/D)+2376.1(1/D^2)$,

$\hat{y}(\text{class I})=110.47-0.8473(D)-1021.44(1/D)+2376.1(1/D^2)$,

$\hat{y}(\text{class II})=108.32-0.8473(D)-1021.44(1/D)+2376.1(1/D^2)$, and

$\hat{y}(\text{class III})=105.08-0.8473(D)-1021.44(1/D)+2376.1(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 8.56 and 0.563.



TOTAL DOLLAR LOSSES

Losses from deterioration after death of trees can be grouped into three categories: (1) Less log volume was delivered and sawn at the sawmill because of breakage; (2) less lumber was recovered from an equivalent volume of dead logs sawn; and (3) the lumber recovered from the dead logs was of lower quality. The total dollar loss in trees is a combination of these losses. The only difference between log value loss and tree value loss is the added effect of breakage in felling and handling.

The most functional form of expressing values is in terms of dollars per hundred cubic feet of tree input. This can be expressed as \$/CCF of gross or net volume. Figure 14 shows the relationship of \$/CCF to tree d.b.h. based on gross and net cubic scales.

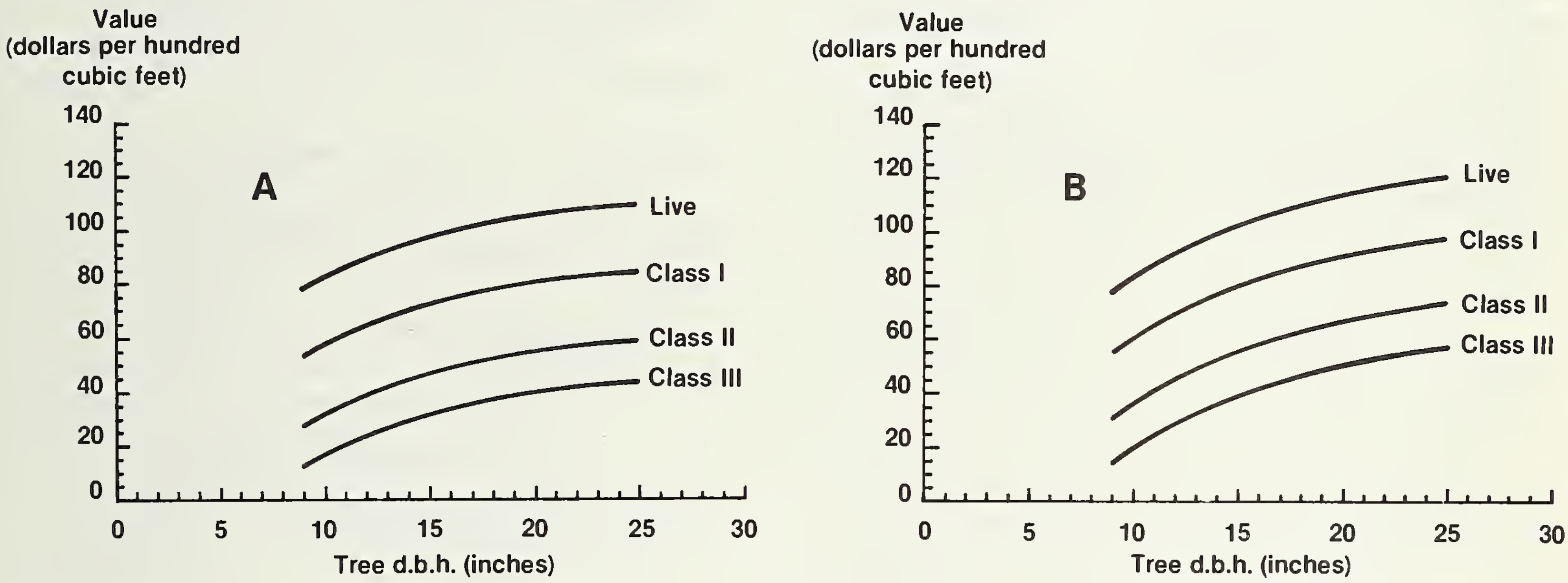


Figure 14.--Lumber values per hundred cubic feet of tree volume by tree d.b.h. and deterioration class, western white pine:

A, gross volume; statistical information--

$\hat{y}(\text{live})=138.98-0.2147(D)-657.70(1/D)+1124.2(1/D^2)$,

$\hat{y}(\text{class I})=114.33-0.2147(D)-657.70(1/D)+1124.2(1/D^2)$,

$\hat{y}(\text{class II})=88.84-0.2147(D)-657.70(1/D)+1124.2(1/D^2)$, and

$\hat{y}(\text{class III})=73.46-0.2147(D)-657.70(1/D)+1124.2(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 16.57 and 0.684.

B, net volume; statistical information--

$\hat{y}(\text{live})135.71+0.4290(D)-669.12(1/D)+973.69(1/D^2)$,

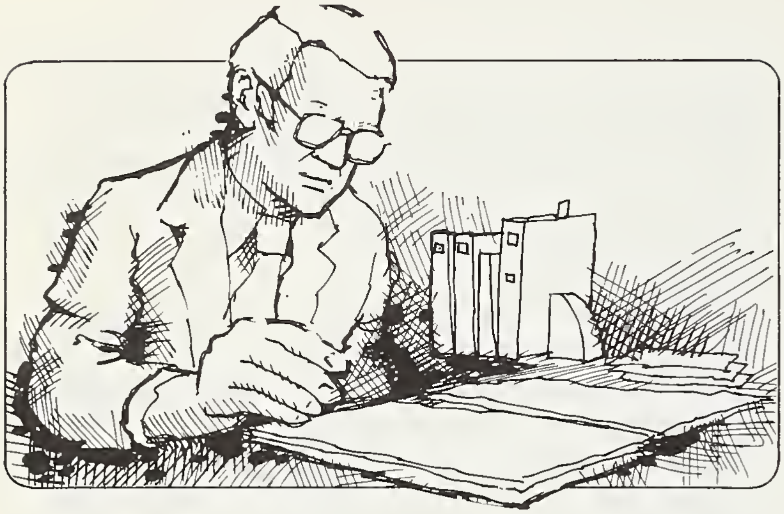
$\hat{y}(\text{class I})=112.97+0.4290(D)-669.12(1/D)+973.69(1/D^2)$,

$\hat{y}(\text{class II})=89.04+0.4290(D)-669.12(1/D)+973.69(1/D^2)$, and

$\hat{y}(\text{class III})=73.02+0.4290(D)-669.12(1/D)+973.69(1/D^2)$.

The standard error of estimate and coefficient of determination (R^2) of the set of curves possessing common regression coefficients but individual class intercepts are, respectively, 16.17 and 0.718.

Analytical Procedures



The data already presented are based on several choices that we made. This section describes how these choices were made. We will cover: (1) the method for choosing curve forms and the resulting curves, (2) derivation of the deterioration classes, and (3) statistical analysis of the various measurement (scaling) systems used in determining volumes from logs and trees.

Model Selection (Curve Form)

This is a documentation of our research experience on types of curves used in representing product recovery for predicting either volume or value. It is not a comprehensive analysis to determine the best possible curve form.

Much information on product recovery (Lane et al. 1973, Henley and Plank 1974, Snellgrove et al. 1975) has been presented in the general equation form of:

Straight line: $\hat{y} = b_0+b_1x_i$;

Quadratic: $\hat{y} = b_0+b_1x;+b_2x_i^2$;

Cubic : $\hat{y} = b_0+b_1x_i+b_2x_i^2+b_3x_i^3$;

where b_0 is $\hat{y}$ intercept constant;

$b_1 \ldots b_3$ are regression coefficients; and

x_i is log diameter.

The dependent variable $\hat{y}$ is product recovery volume expressed as cubic recovery percent or lumber recovery factor, and the independent variable x is log or tree diameter. The dependent variable also may be log or tree values expressed as dollars per thousand board feet of lumber tally ($/MLT), dollars per thousand board feet of net log scale ($/MNLS), or dollars per hundred cubic feet of log input ($/CCF).

In our analysis, we tested the general equations and also used inverse polynomials of the general form:

$$\hat{y} = b_0+b_1x_i.$$

$$\hat{y} = b_0+b_1x_i+b_2/x_i.$$

$$\hat{y} = b_0+b_1x_i+b_2/x_i+b_3/x_i^2.$$

Bruce (1970b) and Fahey (1974) first presented these curve forms for use in product recovery. Woodfin and Snellgrove (1976) also used these curve forms for predicting chip recovery.

In this study, we found that the following general equation consistently performed best in producing the largest R^2 values and smallest standard errors of the estimate:

$$\hat{y} = b_0+b_1x_i+b_2/x_i+b_3/x_i^2.$$

In addition to the statistical validation, it is a very rational curve form. The inverse polynomial curve is more responsive; i.e., has more curvature in lower diameters and approaches an asymptote represented by the linear form ($b_0+b_1x_i$) in the larger diameters. The curve is most flexible where the relationships change most rapidly. Since many product recovery studies initiate sampling in trees, a disproportionate number of small logs are generated--each tree, regardless of its size, produces small logs. Curve forms in the inverse polynomial group allow flexibility in these small diameters and, on the other hand, prevent one or two observations in the larger diameters from drastically altering the shape of the curve.

Deterioration Classes

"Sample Selection" in appendix 1 details the sampling procedure. It also presents the data stratified by diameter and deterioration class. Briefly, the sample was selected on the basis of deterioration class and diameter. These deterioration classes were based on physical appearance of the trees; i.e., bark retention, needle retention, etc. Subsequent to our sample selection, the trees were scrutinized by other researchers and placed into one of seven mortality classes.[14/]

Having the data based on both physical condition of the tree (deterioration classes) and time since death (mortality classes) allowed us to analyze two methods of stratifying dead timber. There are at least two reasons for analyzing the data on the basis of these different systems: (1) It has never been established whether product recovery from dead timber is best related to tree appearance or to time since death; (2) ease of application varies with type of mortality--endemic or epidemic. The first concern implies that, depending on local environmental conditions (e.g., an exposed ridgetop versus a moist bottom site), tree appearance may be a better predictor of product recovery than time since death.

[14/] Research personnel from Potlatch Corporation attempted to date mortality of the sample trees by entomological techniques.

An example could be two trees both killed at the same time, one on a ridge and the other in a protected bottom. Deterioration in the form of drying and checking may be evidenced in the physical appearance of the tree on the exposed site but not in the tree in the protected area. A system relating to time since death would imply the same rate of deterioration in both trees.

The second reason for analyzing deterioration class versus mortality class relates to application; with endemic mortality, it is easier to apply a system based on physical appearance of a tree rather than attempt to date mortality of each tree. The endemic nature of mortality in western white pine suggests physical appearance (deterioration classes) would be better for application. In epidemics where entire stands of timber are killed at the same time and date of mortality is known, it might be easier to use a system based on time since death.

ANALYSIS OF CLASSES

Even after the decision has been made to use deterioration classes, the number of classes must still be decided. Concerns about accuracy and application problems will influence the number of classes used. A system that balances ease of application with accurate predictions and separation between classes is desirable.

The timber cruiser is interested in a system that is easy to apply. Both seller and buyer of dead material are interested in a system that adequately reflects the value of dead timber and can be applied consistently.

The trees were sampled initially on the basis of five deterioration classes plus a live control sample. Is this the optimum system balancing refined accuracy with ease of application? A system using four deterioration classes would be easier to apply, but what impact would this have on accuracy? What about a system that combines all classes of dead--implying that there are no differences in value of dead trees?

Covariance analysis was used to determine if there was a difference between classes and to explain what percent of the variation was explained by regression and separation into classes. As was shown in the previous section, the general model used was:

$$\hat{y} = b_0+b_1x_i+b_2/x_i+b_3/x_i{}^2$$

where:

$\hat{y}$ = $/CCF gross log scale,

$b_0$is y intercept constant, and

b_1, b_2, and b_3 are regression coefficients;

x is the small end log diameter.

Table 12 shows the results of partitioning total sums of squares into individual components. We delineated the portion of total variation in y explained by diameter[15/]and the additional variation accounted for by classes. Since diameter entered the model first, the portion of the variation explained by diameter is constant; therefore, we could evaluate the effect of classes in reducing variation.

[15/]Diameter (D) as used here is represented by three terms: D, 1/D, and $1/D^2$.

We tested the different systems to see if there was a significant increase in errors resulting from reducing the number of classes.

Because of application problems, the seven-class system based on time since death was discarded. There was little difference in variation accounted for between the seven-class system (60 percent), the six-class system (59 percent), and the four-class system (58 percent).

Table 12 and the results of our testing residual sums of squares indicate that the four-class system best balances refined accuracy with practicality in application. In all systems, diameter and classes were sufficiently important in accounting for variation to warrant use of both to predict value. There was a highly significant increase in error when deterioration classes were reduced from six to four as well as from four to two. But the variation accounted for changed substantially only when the four-class system was changed to the two-class system. The significant reduction in errors resulting from increasing the number of dead classes points out the importance of class distinction in obtaining accurate predictions; however, this increase in accuracy had to be balanced with ease of field application.

Table 12--Coefficient of determination (R^2) for 4 evaluation systems for western white pine logs[1]

Evaluation system	Partitions of variation accounted for (R^2) due to:		
	Diameter[2]	Separating into classes[2]	Regressing plus separating into classes
		Percent	
7 classes[3]	26	34	60
6 classes[4]	26	33	59
4 classes[5]	26	32	58
2 classes[6]	26	14	40

[1]Dollars per hundred cubic feet gross log scale is the dependent variable.

[2]Assumes diameter (D) (represented by 3 terms--D, 1/D, and $1/D^2$) enters the model first.

[3]Based on insect dated mortality.

[4]Based on physical appearance.

[5]Derived from analysis of 6 classes.

[6]Comparison of live classes with dead.

We used $/CCF gross log scale as the dependent variable to analyze the classes. As previously shown, this $/CCF is calculated from product volume recovery and product value. Consequently, we can show how regression over diameter and separation of classes affects these individual components of the total variation in $/CCF. When product volume, expressed as cubic recovery percent, is used as the dependent variable, there is a strong relationship with diameter and less difference between classes (see fig. 6). This relationship of cubic recovery percent to diameter is to be expected since product volume is directly related to log diameter. The lack of difference between classes implies that even in the older dead categories a substantial portion of the log was produced as lumber.

When average product value ($/MLT) was predicted, there was virtually no variation accounted by regressing over diameter, but a substantial difference is shown by separating into classes (see tabulation, p. 23). Classes had a strong impact on the quality of lumber produced, whereas the relationship of log diameter to lumber quality is nebulous.

Measurement (Scaling) System Evaluation

The primary purpose of a scaling or measurement system is to facilitate buying and selling timber. Both buyer and seller are well aware of the relationship of product recovery to estimates of log volumes since dollar evaluations of timber are heavily dependent on this relationship. There can be other important uses of a scaling system, but for our study this relationship between log or tree volume and product recovery was of primary importance.

In this study the logs were scaled by several systems: (1) gross Scribner long log, (2) net Scribner long log, (3) gross Scribner short log, (4) net Scribner short log, (5) gross cubic long log, (6) net cubic long log, and (7) cubic product potential long log. For details on application of these scales, see the section on scaling in appendix 1.

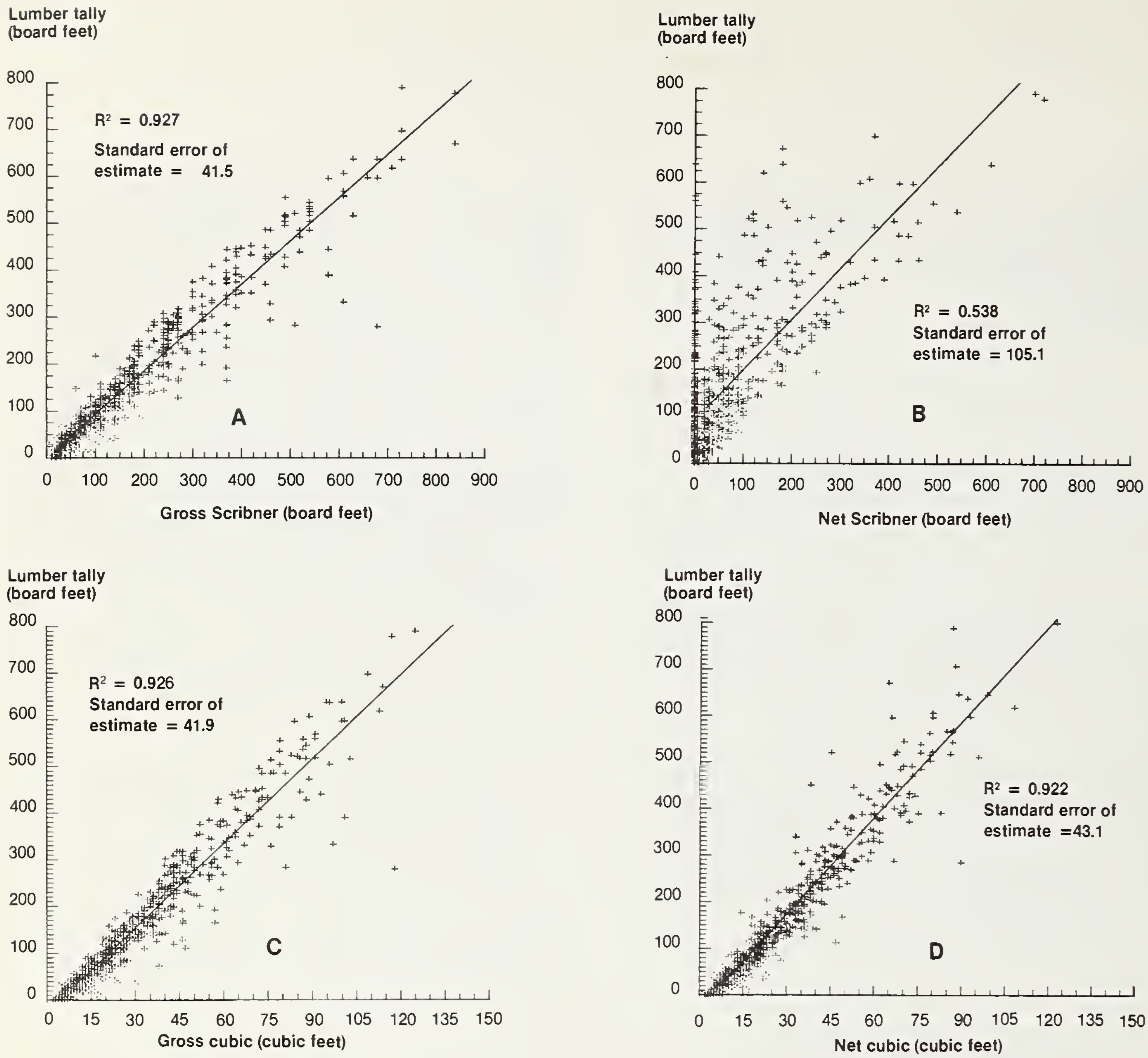
Neither the USDA Forest Service nor industry currently contemplate further use of mill deck scales in Region 1 (Northern Region), so the mill deck (short log) scales are not included in the analysis.

There are a number of ways to evaluate scaling systems, but we used the technique of regressing lumber tally over scale volume. This method has been described in an unpublished report.[16] The dependent variable, lumber tally, is the same for each regression; consequently, R^2 values can be compared directly. The system with the highest R^2 value would be the most precise in predicting lumber tally. Precision is also shown by standard error of the estimate; i.e., the lower the standard error of the estimate, the higher the precision.

Figure 15 shows the scatters for data and the regression lines for the five scaling systems. The wide scatters for net Scribner and cubic product potential indicate a lack of precision, corresponding to the two lowest R^2 values and the highest standard error of the estimate. They are the least precise for predicting lumber tally. Deductions made for net Scribner scale and cubic product potential overestimate defect and account for the wide variability in estimates of lumber tally.

There was virtually no difference in R^2 between gross Scribner and gross and net cubic scale in predicting lumber tally. Gross Scribner volumes are based on the small end of the logs, whereas gross and net cubic are based on large as well as small end diameters. In other samples of logs where taper might be more variable than the taper in this study, the gross or net cubic would probably perform better. Likewise, in samples of logs that have high defects in the form of voids, soft rots, or char, net cubic would probably perform better than either gross Scribner or gross cubic.

[16] Thomas D. Fahey. 1977. Paper presented at the International Forest Products Research Society annual meeting, Denver, Colorado.



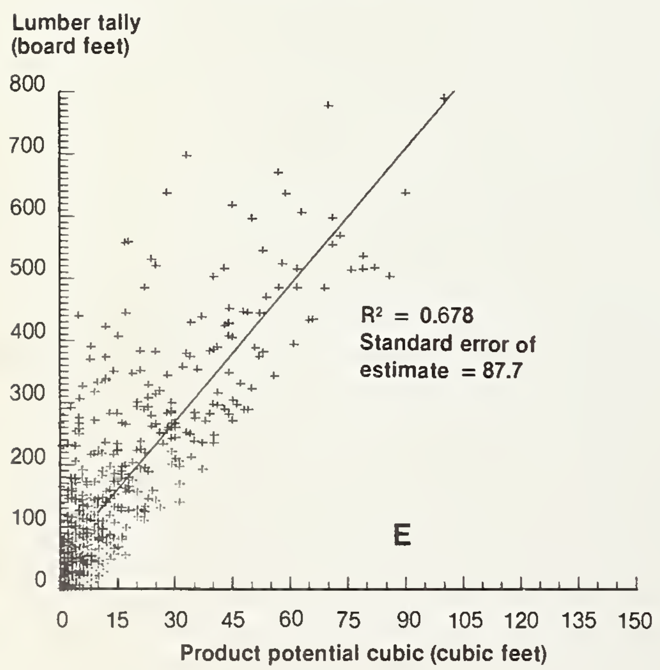


Figure 15.--Analysis of relationship between product volume (lumber tally) and scale volume for various scaling systems, western white pine: A, gross Scribner scale; B, net Scribner scale; C, gross cubic scale; D, net cubic scale; E, product potential cubic scale.

Millions of board feet of western white pine are killed annually by white pine blister rust and the mountain pine beetle, yet less than 10 percent of this mortality is salvaged. This report provides tools for resource managers and the forest products industry to make decisions that can increase utilization of this dead material. It also provides a framework and guidelines for future research on dead timber.

We recommend a four-class system for stratifying live and dead timber. This includes three classes of dead timber ranging from recent dead to older dead material.

Log Information

Development of defect.--When a tree dies, it undergoes a series of changes that will affect product recovery. These changes include staining, heart checking (splitting), surface checking, weathering, and a general increase in sap rots and wood borer damage. Moisture and temperature conditions exert the greatest control on deterioration, and any environmental factors that control moisture or temperature will in turn influence deterioration. Because of the variety of conditions that can occur on a single timber sale, understanding the basic relationship between environmental factors and deterioration is as important as the specific rates of deterioration encountered.

Defect estimation.--Estimated defect varies substantially, depending on the types of defect and the scaling system used for measurement. Three systems for measuring defect were used in this study: net Scribner, which attempts to predict volume of lumber in board feet; net cubic, which attempts to predict chippable log volume; and product potential cubic, which attempts to predict log volume suitable for solid wood products.

Defect percent increased as time since death increased in all three systems. Estimates were highest with net Scribner and cubic product potential as the basis for measurement; net cubic showed the lowest defect percents. Differences between net Scribner and product potential cubic were primarily due to techniques used to measure and compute defects.

Relationship of defect, scale, and product recovery.--Estimates of defect are most important in terms of product recovery, and product recovery is most meaningful when explained in terms of how the logs were measured. There should be a relationship between predicted sound log volume and actual lumber volume recovered.

Net Scribner scale and cubic product potential overestimated the impact of defects on actual volume of products; net cubic scale underestimated the impact. Volume deductions for checks in net Scribner and cubic product potential far exceed the actual lumber loss. Net cubic underestimates the impact of defects on lumber volume recovered because it is intended to predict chippable volume rather than lumber volume. The most accurate estimates of sound log volume in relationship to lumber volume was between net cubic and product potential cubic.

Product Recovery

The relationship of product volume to log volume can be expressed as recovery ratio (overrun), cubic recovery percent, or lumber recovery factor. Even though overrun based on net Scribner is the most common method of representing product recovery in the West, for our study it was the poorest system. Overrun based on net Scribner scale increased from live through the older dead classes of logs, indicating defect deductions were excessive.

Cubic recovery percent and lumber recovery factor best represent the relationship of sawn product volume to log volume. In both systems, when lumber recovery was based on either gross or net cubic scale, recovery decreased from live through the classes. In recently killed trees (class I), drying checks were the primary cause of the reduction in lumber volume. Additional losses in older dead material were due mainly to weathering, sap rots, and borers.

Chip yields are the complement to the cubic lumber recovery; i.e., smaller logs produced less lumber, thus more chips per unit of volume. Also, logs from live and recently killed trees produced more lumber and less chips, whereas older dead trees produced more chips and less lumber.

Lumber yields.--There is a substantial difference in lumber quality between live and dead timber. Live trees produce a high percentage of No. 2 Common and Better and Shop grades, whereas the older dead material produces more No. 4 and 5 Common. In the most recent dead material, lumber degrade was caused by blue stain and by splits from drying. Wormholes were present but not prevalent in the dead logs; even when present, they had a minor impact on lumber grade. Loss of lumber grade was greatest in highest quality logs because there was more grade to lose.

Lumber width decreased as time since death increased. This reduces the value and marketability of the lumber.

Dollars per thousand board feet of lumber tally were used to represent the average value of lumber produced. The $/MLT decreased by about 50 percent from live trees to the oldest dead class. This decrease in value is a reflection of both lower quality lumber and narrower widths.

Log value.--Losses of log value in dead timber result from a combination of losses of lumber volume and value. Total losses are represented by dollars per hundred cubic feet of either gross or net cubic scale. The $/CCF decrease from live through the class III logs. Log value also decreases with a decrease in diameter; consequently, both size and deterioration class should be considered when values of logs are estimated. When this total loss of value was apportioned to either lumber volume or lumber value, the greatest initial loss was due to lumber value. In older dead material, the loss of lumber volume increased in importance.

Chip yields have a significant impact on the value of the marginal log; when chips can be marketed, they may mean the difference between a log's being profitable or unprofitable. Adding in the value of chips also reduces the differences between deterioration classes because some lumber recovery loss is offset by the increased production of chips.

Tree Information

With the exception of logging and handling losses, all effects of deterioration can best be described in terms of logs. Logging and handling losses are primarily a reflection of losses from breakage. As wood dries, it becomes more brash, so breakage increases with time since death. In general, this breakage will decrease the volume of logs of preferred length delivered to the mill. This increased percent of off-length log volume is not as significant in mills processing random-length logs as in mills requiring specified lengths, such as stud mills.

Lumber volume recovery in trees shows the same pattern as for logs; it decreases from live through the classes. The relationship of diameter to product recovery in trees is important, but the averaging effect of small logs in large trees causes the curve to be more gradual.

The total dollar losses in dead trees is a combination of the losses of lumber volume and value plus the effect of increased breakage. As with logs, the most functional form of expressing tree values is in dollars per hundred cubic feet of tree volume. The $/CCF decrease from live through the classes and also decrease with a decrease in diameter. Diameter as well as deterioration class should be considered when log values are expressed.

Analytical Procedures

Model selection (curve form).--Six general equations were tested for predicting product recovery and product value. The general equation,

$$\hat{y}=b_0+b_1x_i+b_2/x_i+b_3/x_i^2,$$

performed best, as measured by R^2 and standard error of the estimate. This inverse polynomial curve allows flexibility in small diameters. It also prevents small numbers of observations in the larger diameters from drastically altering the shape of the curve as often happens in conventional polynomial curves.

Analysis of deterioration classes.--The sample was stratified based on physical appearance of the trees (deterioration classes) and on time since death (mortality classes). Time since death was disregarded as an effective way to classify dead western white pine because of the difficulty of determining the time. Several regimes of deterioration classes were analyzed to determine the systems that best balanced ease of application with accurate predictions. A system based on one live and three dead classes of material balanced ease of application with refined accuracy. For this four-class system, the advantage from separating material into classes exceeded the advantage of regressing over diameter, when evaluated on the basis of variation accounted for.

Measurement (scaling) system evaluation.--Seven log scales were applied to the study logs. These were all variations of either Scribner or cubic scaling methods. All scales taken on the mill deck were discarded because of limited use. The other scales were evaluated on the basis of their ability to predict lumber tally volume. Gross Scribner scale and gross cubic and net cubic scales performed about equally well in predicting lumber tally, based on R^2 values and standard error of the estimate. Net Scribner scale, the commonly used system of log measurement in the West, performed the poorest. This analysis confirms that net Scribner and product potential cubic overestimated the impacts of defects for this study, whereas net cubic underestimated the impact.

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Appendix 1

Field Procedures

SAMPLE SELECTION

Selecting samples of dead timber differs from selecting live samples. Beyond the normal variation of size and quality, another variable is superimposed. Time since death becomes an important factor. The population of dead trees ranges from trees that have foliage just beginning to fade to trees that are devoid of bark and limbs.

To fulfill the objectives of our study, we used two approaches to stratifying our sample. First, we used a system that related directly to deterioration based on physical appearance of the tree; i.e., needle retention, bark retention, persistence of twigs, etc. Second, we used a system that attempted to date mortality more directly. For instance, approximate date of death was correlated with entomological characteristics--the presence of insects, insect pitch tubes, condition of pitch tubes, etc.

The study trees were selected on the Clearwater National Forest in Idaho. Individual trees were selected on the basis of d.b.h., physical appearance relating to deterioration, and stem quality. Primary emphasis for sample selection was on d.b.h. and deterioration, with an arbitrary estimate of stem quality. Efforts were taken to insure that the sample was representative of the size and quality of western white pine trees from 9- to 34-inch d.b.h. No larger trees were selected, so application of these results should be restricted to this d.b.h. range.

Deterioration was estimated in the form of needle and bark characteristics. A description of the deterioration categories is as follows:

Live:	Living trees, green foliage.
Class I:	Needles present, 100-percent tight bark in merchantable bole.
Class II:	Needles present, bark beginning to loosen in merchantable bole.
Class III:	No needles, 90-percent and greater bark retention.
Class IV:	No needles, 25- to 89-percent bark retention.
Class V:	No needles, less than 25-percent bark retention.

Table 13 shows the distribution of sample trees by deterioration class and diameter.

Table 13--Distribution of sample trees by deterioration class, western white pine

Deterioration class	Number of trees	D.b.h. Range	D.b.h. Average[1]
		- - -Inches- - -	
Live	17	10-33	22.5
Class I	32	9-28	19.5
Class II	29	13-29	21.2
Class III	43	9-34	21.2
Class IV	42	10-31	20.9
Class V	31	9-28	19.9
Total or average	194	9-34	20.8

[1]D.b.h. average is the quadratic mean.

After the sample was selected, the date of mortality was estimated.[1/] This stratification by time since death (mortality codes) was only used in the comparison of mortality codes with deterioration classes. We rejected use of the mortality codes because of difficulty in application; consequently, no details on stratification by this method are presented.

LOGGING, IDENTIFICATION, AND HAULING

The study trees were felled and bucked into saw logs by cooperating logging contractors according to normal industry practice in the area. No unusual felling or handling practices were used in the study. Each log was tagged in the woods to identify its origin with tree and position in the tree. All logs were skidded by tractor or rubber-tired equipment. According to normal practice, logs were bucked to "preferred lengths" for the cooperating mill when possible. In this study "preferred length" was 32 feet plus trim. The logs were hauled to the mill in these lengths. Log breakage was identified and quantified in the study.

SCALING

All logs delivered to the mill were scaled by USDA Forest Service "check scalers." The logs were rolled out in the yard and a long-log Scribner scale and cubic scale were taken. A mill deck short-log scale was also taken just before the logs were sawed.

Both Scribner scales were taken in accordance with the National Forest Service Log Scaling Handbook of 1974.

Cubic measurements were taken in accordance with the proposed National Forest Service Cubic Scaling Handbook of June 1974. Three cubic volume estimates were taken:

1. Gross cubic scale--based on overall log dimensions.
2. Net cubic scale--based on gross cubic scale minus deductions for voids, soft rots, and charred wood. It is intended to predict the volume of a log that is suitable to produce a solid chip.
3. Product potential cubic--based on gross cubic scale minus deductions for any defects that are supposed to limit lumber tally volume. Diameters were recorded in accordance with the cubic scaling handbook, but log lengths were recorded as actual log length to the nearest one-tenth cf a foot.

LUMBER MANUFACTURING

Sawing, drying, and surfacing practices of the mill were representative of general industry practice in that area. Log identity was maintained on each piece of lumber through the manufacturing process to the final point of grade tally.

[1/] Research personnel from Potlatch Corporation attempted to date mortality of the sample trees.

Sawing, Drying, and Surfacing

The study logs were sawn with the objective of obtaining the highest value from each log. Logs up to and including 20 feet in length were sawn. Lumber on the green chain did not exceed 16 feet because longer items were cut into two pieces. Shop items were sawn to 5/4-inch thickness and all other items to 4/4 inch.

Production equipment in the sawmill included a double-cut band headrig, a bull edger, and a 24-foot gang trim saw.

After the logs were sawn, all study lumber was kiln dried and surfaced. Kiln schedules were adjusted to compensate for the drier lumber produced from dead trees.

Lumber Grading and Tallying

A Western Wood Products Association grading inspector either graded or supervised the grading of study lumber on the planer chain. All study lumber was graded under the Western Wood Products Association "1970 Standard Grading Rules for Western Lumber."

Each lumber item produced was placed in one of the following grades:

B and Better (Supreme)	No. 2 Shop
C Select (Choice)	No. 1 Common (Colonial)
D Select (Quality)	No. 2 Common (Sterling)
Molding	No. 3 Common (Standard)
No. 3 Clear	No. 4 Common (Utility)
No. 1 Shop	No. 5 Common (Industrial)

Each board was tallied by its shipping dimensions, grade, and log number.

CUBIC CALCULATIONS

Log Volumes

Cubic-foot log volumes were calculated by Smalian's formula, except for butt logs.[2/] Volumes of butt logs were estimated by an equation for butt logs (Bruce 1970a).

Lumber, Sawdust, Planer Shavings, and Shrinkage

Cubic volumes of lumber were based on the size of either rough green boards or surfaced dry boards. The sizes of rough green boards were determined from measurement of a random sample of widths and thicknesses of boards taken as lumber was pulled from the green chain. Three measurements were made per board--one near each end of the board and one near the middle. Sizes of surfaced dry lumber were derived by applying actual finished sizes to all the lumber tally volume.

[2/] The formula for the frustrum of a paraboloid is often referred to as Smalian's formula:

$$V = l(A_s+A_l)/2;$$

where:

V = volume in cubic units,

l = total length in linear units,

A_s = cross-sectional area in square units at small end, and

A_l = cross-sectional area in square units at large end.

Cubic volumes of sawdust were calculated by using an average saw kerf and the computed surface area of the rough green lumber. Volumetric shrinkage and volumes of planer shavings were not separated; they were calculated by subtracting the cubic volume of surfaced dry lumber from the cubic volume of rough green lumber.

Chip Volumes and Weights

Our general method of calculating chippable volumes and converting these volumes to weight can be shown by the following steps:

(Gross cubic log volume) - (deductions for voids, soft rots, and char) = net cubic log volume.

(Net cubic log volume) - (rough green lumber and sawdust volumes) = estimated chippable volume.

(Estimated chippable volume)(density) = weight of chips.

The specific method of determining weight of chips follows:

1. Determine specific gravity for western white pine.[3]

2. Adjust specific gravity for varying moisture content of dead trees. Moisture contents used were 92 percent for live, 32 percent for class I, 20 percent for class II, and 16 percent for class III (see footnote 3). Using specific gravity of 0.39 and these moisture contents, determine the adjusted specific gravity (Forest Products Laboratory 1974).

3. Using adjusted specific gravity, determine ovendry density by multiplying by the density of water (62.4 pounds per cubic foot). The densities were: live, 24.3 pounds per cubic foot; class I, 24.3; class II, 25.3; and class III, 25.6. Density is based on green volume and ovendry weight. Because dead material (with moisture contents below fiber saturation point) has undergone some shrinkage, densities increased in the older dead material.[4]

4. Multiply density by chippable volume to determine pounds per cubic foot for each log.

[3] Specific gravity taken from final report of a cooperative study by Pacific Northwest Forest and Range Experiment Station and Washington State University College of Engineering, Research Division, 1975. Standing dead white pine and dead lodgepole pine as raw material for composition board. Res. Rep. 75/57-39, 42 p., and appendixes. On file at Pacific Northwest Forest and Range Experiment Station.

[4] Fiber saturation point is defined as point at which all water is evaporated from the cell cavities but the cell walls are still fully saturated with moisture--generally about 30 percent moisture content based on ovendry weight.

Appendix 2

Table 14--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--woods-length, live western white pine logs

Log scaling diameter[1]	Number of logs	Cubic log scale[2]		Cubic defect[3]	Lumber tally volume	Lumber recovery factor[4]		Cubic volume[5]				Cubic lumber recovery[6]	
		Gross	Net			Gross	Net	Lumber	Sawdust	Chippable	Nonchippable	Gross	Net
Inches		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--Cubic feet--				Percent	
6	4	36.85	36.85	0	75	2.04	2.04	6.43	1.20	29.22	0	17	17
7	6	60.23	60.23	0	197	3.27	3.27	16.60	3.07	40.56	0	28	28
8	5	54.48	54.48	0	233	4.28	4.28	20.45	3.55	30.48	0	38	38
9	2	42.49	42.49	0	240	5.65	5.65	20.53	3.66	18.30	0	48	48
10	4	67.69	65.69	3.0	312	4.61	4.75	27.65	4.74	33.30	2.0	41	42
11	3	92.55	92.55	0	494	5.34	5.34	44.46	7.26	40.83	0	48	48
12	5	198.32	198.32	0	1,147	5.78	5.78	102.08	17.01	79.23	0	51	51
13	5	152.09	152.09	0	904	5.94	5.94	83.22	12.93	55.94	0	55	55
14	1	40.43	40.43	0	234	5.79	5.79	22.10	3.33	15.00	0	55	55
15	3	149.80	149.80	0	908	6.06	6.06	83.52	12.89	53.39	0	56	56
16	5	246.38	245.38	0.4	1,527	6.20	6.22	140.36	21.79	83.23	1.0	57	57
17	1	68.05	67.05	1.5	395	5.80	5.89	36.81	5.50	24.74	1.0	54	55
18	--	--	--	--	--	--	--	--	--	--	--	--	--
19	3	199.57	199.57	0	1,384	6.93	6.93	121.15	20.21	58.21	0	61	61
20	2	183.12	183.12	0	1,040	5.68	5,68	94.19	14.90	74.03	0	51	51
21	2	165.37	164.37	0.6	1,071	6.48	6.52	100.08	14.83	49.46	1.0	60	61
22	--	--	--	--	--	--	--	--	--	--	--	--	--
23	2	242.79	210.79	13.2	1,570	6.47	7.45	145.02	22.07	43.70	32.0	60	69
Total or average	53	2,000.21	1,963.21	1.8	11,731	5.86	5.98	1,064.65	168.94	729.62	37	53	54

[1] In accordance with proposed national USDA Forest Service Cubic Scaling Handbook as of June 1974.

[2] As scaled by USDA Forest Service scalers applying the proposed USDA Forest Service Cubic Scaling Handbook rules as of June 1974; length recorded as actual log length to nearest 1/10 foot.

[3] Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[4] Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[5] Lumber and sawdust volumes are based on rough green dimensions. Chippable volume = (gross cubic scale - lumber, sawdust, and nonchippable cubic volume). Nonchippable volume = (gross cubic scale - net cubic scale) which is the volume of voids, soft rots, and char.

[6] Gross = (lumber cubic volume/gross log cubic volume)(100); net = (lumber cubic volume/net log cubic volume)(100).

Table 15--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--woods-length, deterioration class I western white pine logs

Log scaling diameter[1]	Number of logs	Cubic log scale[2] Gross	Net	Cubic defect[3]	Lumber tally volume	Lumber recovery factor[4] Gross	Net	Cubic volume[5] Lumber	Sawdust	Chippable	Nonchippable	Cubic lumber recovery[6] Gross	Net
Inches		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--Cubic feet--				Percent	
5	3	16.87	16.87	0	28	1.66	1.66	2.33	.10	14.08	0	14	14
6	11	50.86	49.86	2.0	88	1.73	1.76	7.30	1.31	41.25	1.0	14	15
7	18	182.76	180.76	1.1	638	3.49	3.53	53.35	9.84	117.57	2.0	29	30
8	18	204.60	199.60	2.4	799	3.90	4.00	75.04	14.16	110.40	5.0	37	38
9	13	167.66	166.66	0.6	725	4.32	4.35	61.21	10.98	94.47	1.0	36	37
10	17	285.49	280.49	1.8	1,461	5.12	5.21	126.04	22.37	132.08	5.0	44	45
11	18	332.41	330.41	0.6	1,596	4,80	4.83	137.71	24.15	168.55	2.0	41	42
12	21	532.86	527.86	0.9	2,803	5.26	5.31	247.80	41.83	238.23	5.0	46	47
13	18	586.47	573.47	2.2	3,300	5,63	5.75	289.04	49.34	235.09	13.0	49	50
14	14	594.53	584.53	1.7	3,582	6.02	6.13	315.52	53.06	215.95	10.0	53	54
15	12	546.19	521.19	4.6	3,177	5.82	6.10	281.86	46.83	192.50	25.0	52	54
16	7	374.21	354.21	5.3	2,319	6.20	6.55	203.27	34.20	116.74	20.0	54	57
17	8	406.91	398.91	2.0	2,420	5.95	6.07	182.72	35.42	180.77	8.0	45	46
18	9	647.36	610.36	5.7	3,915	6.05	6.41	350.08	56.85	203.43	37.0	54	57
19	9	623.55	575.55	7.7	3,710	5.95	6.45	325.93	54.95	194.67	48.0	52	57
20	1	91.40	87.40	4.4	569	6.22	6.51	54.46	7.79	25.15	4.0	60	62
21	3	290.18	253.18	12.8	1,802	6.21	7.12	158.13	26.56	68.49	37.0	54	62
Total or average	200	5,934.31	5,711.31	3.8	32,932	5.55	5.77	2,871.79	490.10	2,349.42	223.0	48	50

[1]In accordance with proposed national USDA Forest Service Cubic Scaling Handbook as of June 1974.

[2]As scaled by USDA Forest Service scalers applying the proposed USDA Forest Service Cubic Scaling Handbook rules as of June 1974; length recorded as actual log length to nearest 1/10 foot.

[3]Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[4]Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[5]Lumber and sawdust volumes are based on rough green dimensions. Chippable volume = (gross cubic scale - lumber, sawdust, and nonchippable cubic volume). Nonchippable volume = (gross cubic scale - net cubic scale) which is the volume of voids, soft rots, and char.

[6]Gross = (lumber cubic volume/gross log cubic volume)(100); net = (lumber cubic volume/net log cubic volume)(100).

Table 16--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--woods-length, deterioration class II western white pine logs

Log scaling diameter[1]	Number of logs	Cubic log scale[2]		Cubic defect[3]	Lumber tally volume	Lumber recovery factor[4]		Cubic volume[5]				Cubic lumber recovery[6]	
		Gross	Net			Gross	Net	Lumber	Sawdust	Chippable	Nonchippable	Gross	Net
Inches		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		----------------Cubic feet----------------				Percent	
5	2	14.70	14.70	0	0	0	0	0	0	14.70	0	0	0
6	6	48.26	48.26	0	117	2.42	2.42	9.91	1.81	36.54	0	20	20
7	8	62.66	62.66	0	122	1.95	1.95	10.21	1.86	50.59	0	16	16
8	13	168.13	168.13	0	665	3.96	3.96	56.39	10.16	101.58	0	34	34
9	8	96.06	92.06	4.2	377	3.92	4.10	32.13	5.82	54.11	4.0	33	35
10	14	198.36	197.36	.5	874	4.41	4.43	74.57	13.36	109.43	1.0	38	38
11	9	220.75	217.75	1.4	1,123	5.09	5.16	96.81	16.91	104.03	3.0	44	44
12	14	368.16	359.16	2.4	1,625	4.41	4.52	142.24	24.42	192.50	9.0	39	40
13	5	126.71	115.71	8.7	651	5.14	5.63	55.93	9.91	49.87	11.0	44	48
14	14	506.76	471.76	6.9	2,887	5.70	6.12	251.66	43.42	176.68	35.0	50	53
15	9	298.16	287.16	3.7	1,616	5.42	5.63	141.50	24.27	121.39	11.0	47	49
16	5	139.70	126.70	9.3	700	5.01	5.52	61.66	10.37	54.67	13.0	44	49
17	8	505.33	442.33	12.5	3,138	6.21	7.09	271.36	46.65	124.32	63.0	54	61
18	4	215.59	188.59	12.5	1,108	5.14	5.88	96.98	16.42	75.19	27.0	45	51
19	4	341.36	267.36	21.7	2,039	5.97	7.63	180.03	30.13	57.20	74.0	53	67
20	4	299.71	263.71	12.0	1,711	5.71	6.49	149.38	25.41	88.92	36.0	50	57
21	1	36.32	27.32	24.8	218	6.00	7.98	18.89	3.25	5.18	9.0	52	69
22	1	101.15	83.15	17.8	389	3.84	4.68	34.71	5.66	42.78	18.0	34	42
23	3	323.26	255.26	21.0	1,927	5.96	7.55	169.72	28.52	57.02	68.0	52	66
Total or average	132	4,071.13	3,689.13	9.4	21,287	5.23	5.77	1,854.08	318.35	1,516.70	382.0	46	50

[1]In accordance with proposed national USDA Forest Service Cubic Scaling Handbook as of June 1974.

[2]As scaled by USDA Forest Service scalers applying the proposed USDA Forest Service Cubic Scaling Handbook rules as of June 1974; length recorded as actual log length to nearest 1/10 foot.

[3]Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[4]Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[5]Lumber and sawdust volumes are based on rough green dimensions. Chippable volume = (gross cubic scale - lumber, sawdust, and nonchippable cubic volume). Nonchippable volume = (gross cubic scale - net cubic scale) which is the volume of voids, soft rots, and char.

[6]Gross = (lumber cubic volume/gross log cubic volume)(100); net = (lumber cubic volume/net log cubic volume)(100).

Table 17--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--woods-length, deterioration class III western white pine logs

Log scaling diameter[1]	Number of logs	Cubic log scale[2]		Cubic defect[3]	Lumber tally volume	Lumber recovery factor[4]		Cubic volume[5]				Cubic lumber recovery[6]	
		Gross	Net			Gross	Net	Lumber	Sawdust	Chippable	Nonchippable	Gross	Net
Inches		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		----Cubic feet----				Percent	
5	2	10.95	10.95	0	16	1.46	1.46	1.28	.25	9.42	0	12	12
6	14	89.30	84.30	5.6	130	1.46	1.54	10.92	2.01	71.37	5.0	12	13
7	14	152.34	145.34	4.6	463	3.04	3.19	39.33	6.87	99.14	7.0	26	27
8	20	224.12	218.12	2.7	592	2.64	2.71	49.86	9.33	158.93	6.0	22	23
9	18	274.58	254.58	7.3	977	3.56	3.84	83.12	15.14	156.32	20.0	30	33
10	16	285.72	266.72	6.6	1,052	3.68	3.94	89.35	15.99	161.38	19.0	31	34
11	19	452.96	420.96	7.1	1,623	3.58	3.86	138.77	25.12	257.07	32.0	31	33
12	18	413.71	372.71	9.9	1,580	3.82	4.24	136.62	23.70	212.39	41.0	33	37
13	23	702.56	614.56	12.5	3,269	4.65	5.32	282.60	49.86	282.10	88.0	40	46
14	11	413.09	332.09	19.6	2,061	4.99	6.21	179.23	29.15	123.71	81.0	43	54
15	15	711.50	594.50	16.4	3,368	4.73	5.66	289.82	52.02	252.66	117.0	41	49
16	6	342.86	274.86	19.8	1,589	4.63	5.78	136.40	24.12	114.34	68.0	40	50
17	13	693.22	601.22	13.3	3,813	5.50	6.34	329.82	57.45	213.95	92.0	48	55
18	7	384.08	305.08	20.6	1,723	4.49	5.65	148.04	26.10	130.94	79.0	38	48
19	2	92.79	82.79	10.8	383	4.13	4.63	33.08	5.78	43.93	10.0	36	40
20	8	633.63	477.63	24.6	3,324	5.25	6.96	286.44	50.17	141.02	156.0	45	60
21	4	300.95	242.95	19.3	1,559	5.18	6.42	134.76	23.50	84.69	58.0	45	55
22	2	212.98	178.98	16.0	918	4.31	5.13	79.24	13.85	85.89	34.0	37	44
23	2	160.11	133.11	16.9	1,050	6.56	7.89	90.55	15.74	26.82	27.0	56	68
Total or average	214	6,551.45	5,611.45	14.3	29,490	4.50	5.26	2,539.23	445.15	2,626.07	940.0	39	45

1/In accordance with proposed national USDA Forest Service Cubic Scaling Handbook as of June 1974.

2/As scaled by USDA Forest Service scalers applying the proposed USDA Forest Service Cubic Scaling Handbook rules as of June 1974; length recorded as actual log length to nearest 1/10 foot.

3/Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

4/Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

5/Lumber and sawdust volumes are based on rough green dimensions. Chippable volume = (gross cubic scale - lumber, sawdust, and nonchippable cubic volume). Nonchippable volume = (gross cubic scale - net cubic scale) which is the volume of voids, soft rots, and char.

6/Gross = (lumber cubic volume/gross log cubic volume)(100); net = (lumber cubic volume/net log cubic volume)(100).

Table 18--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--all woods-length western white pine logs

Log scaling diameter[1]	Number of logs	Cubic log scale[2] Gross	Cubic log scale[2] Net	Cubic defect[3]	Lumber tally volume	Lumber recovery factor[4] Gross	Lumber recovery factor[4] Net	Cubic volume[5] Lumber	Cubic volume[5] Sawdust	Cubic volume[5] Chippable	Cubic volume[5] Nonchippable	Cubic lumber recovery[6] Gross	Cubic lumber recovery[6] Net
Inches		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		----------------Cubic feet----------------				Percent	
5	7	42.52	42.52	0	44	1.03	1.03	3.61	.71	38.20	0	8	8
6	35	225.27	219.27	2.7	410	1.82	1.87	34.56	6.33	178.38	6.0	15	16
7	46	457.99	448.99	2.0	1,420	3.10	3.16	119.49	21.64	307.86	9.0	26	27
8	56	651.33	640.33	1.7	2,289	3.51	3.57	201.74	37.20	401.39	11.0	31	32
9	41	580.79	555.79	4.3	2,319	3.99	4.17	196.99	35.60	323.20	25.0	34	35
10	51	837.26	810.26	3.2	3,699	4.42	4.56	317.61	56.46	436.19	27.0	38	39
11	49	1,098.67	1,061.67	3.4	4,836	4.40	4.56	417.75	73.44	570.48	37.0	38	39
12	58	1,513.05	1,458.05	3.6	7,155	4.73	4.91	628.74	106.96	722.35	55.0	42	43
13	51	1,567.83	1,455.83	7.1	8,124	5.18	5.58	710.79	122.04	623.00	112.0	45	49
14	40	1,554.81	1,428.81	8.1	8,764	5.64	6.13	768.51	128.96	531.34	126.0	49	54
15	39	1,705.65	1,552.65	9.0	9,069	5.32	5.84	796.70	130.01	619.94	153.0	47	51
16	23	1,103.15	1,001.15	9.2	6,135	5.56	6.13	541.69	90.48	368.98	102.0	49	54
17	30	1,673.51	1,509.51	9.8	9,766	5.84	6.47	820.71	145.02	543.78	164.0	49	54
18	20	1,247.03	1,104.03	11.5	6,746	5.41	6.11	595.10	99.37	409.56	143.0	48	54
19	18	1,257.27	1,125.27	10.5	7,516	5.98	6.68	660.19	111.07	354.01	132.0	52	59
20	15	1,207.86	1,011.86	16.2	6,644	5.50	6.57	584.47	98.27	329.12	196.0	48	58
21	10	792.82	687.82	13.2	4,650	5.86	6.76	411.86	68.14	207.82	105.0	52	60
22	3	314.13	262.13	16.6	1,307	4.16	4.99	113.95	19.51	128.67	52.0	36	43
23	7	726.16	599.16	17.5	4,547	6.26	7.59	405.29	66.33	127.54	127.0	56	68
Total or average	599	18,557.10	16,975.10	8.5	95,440	5.14	5.62	8,329.75	1,423.54	7,221.81	1,582.0	45	49

[1]In accordance with proposed national USDA Forest Service Cubic Scaling Handbook as of June 1974.

[2]As scaled by USDA Forest Service scalers applying the proposed USDA Forest Service Cubic Scaling Handbook rules as of June 1974; length recorded as actual log length to nearest 1/10 foot.

[3]Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[4]Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[5]Lumber and sawdust volumes are based on rough green dimensions. Chippable volume = (gross cubic scale - lumber, sawdust, and nonchippable cubic volume). Nonchippable volume = (gross cubic scale - net cubic scale) which is the volume of voids, soft rots, and char.

[6]Gross = (lumber cubic volume/gross log cubic volume)(100); net = (lumber cubic volume/net log cubic volume)(100).

Table 19--Total lumber production by dimension and grade--live western white pine logs

Lumber dimension	C Select	D Select	3 Clear	1 Shop	2 Shop	3 Shop	1 Common	2 Common	3 Common	4 Common	5 Common	Total
Inches	Percent											
1x4	0.36	0.84	0	0	0	0	0.42	0.78	3.38	1.47	0.25	7.50
1x6	.12	.55	.14	1.47	.12	0	.13	1.99	4.21	1.50	.09	10.31
1x8	.10	.14	.09	.31	.58	0	.07	1.02	5.07	1.96	.07	9.41
1x10	.06	0	.22	.95	.34	0	.07	2.94	7.54	1.59	0	13.71
1x12	.14	0	1.02	1.16	.77	0	.24	5.71	17.30	4.28	.38	30.99
5/4x4	0	.04	0	0	0	0	0	.04	.03	.05	0	.18
5/4x6	0	.30	0	0	.22	0	0	1.14	.50	.08	0	2.24
5/4x8	.10	.41	0	.11	.34	.61	0	2.94	1.85	.15	0	6.51
5/4x10	.14	.35	0	.52	.45	.14	0	3.45	3.09	.23	0	8.39
5/4x12	0	0	0	.66	.13	0	0	5.64	4.17	.15	0	10.76
Total	1.02	2.63	1.47	5.17	2.95	.75	.92	25.67	47.16	11.48	.78	100.00

Table 20--Total lumber production by dimension and grade--deterioration class I western white pine logs

Lumber dimension	C Select	D Select	3 Clear	1 Shop	2 Shop	3 Shop	1 Common	2 Common	3 Common	4 Common	5 Common	Total
Inches						Percent						
1x4	0.05	0.46	0	0	0	0	0.21	0.50	3.53	2.65	0.30	7.70
1x6	.05	.22	0	.13	.12	0	.12	1.72	7.96	4.79	.36	14.57
1x8	.04	.15	.02	.25	.22	0	.08	1.08	9.25	5.59	.29	16.96
1x10	0	.07	0	.49	0	0	.22	2.17	12.84	4.63	.16	20.59
1x12	0	0	.26	.93	.49	0	.33	3.70	17.22	6.09	.30	29.32
5/4x4	0	.02	0	0	0	0	0	0	.07	.02	0	.12
5/4x6	.02	.03	0	0	0	0	0	.15	.20	0	0	.40
5/4x8	0	.06	0	0	.04	0	0	.71	.86	.04	0	1.71
5/4x10	0	.10	0	.10	0	.09	0	1.59	1.13	.22	0	3.24
5/4x12	0	0	0	0	.06	.17	0	2.99	1.15	.12	0	4.49
Total	.16	1.13	.27	1.90	.94	.26	.95	14.61	54.20	24.16	1.42	100.00

Table 21--Total lumber production by dimension and grade--deterioration class II western white pine logs

Lumber dimension	C Select	D Select	3 Clear	1 Shop	2 Shop	3 Shop	1 Common	2 Common	3 Common	4 Common	5 Common	Total
Inches						Percent						
1x4	0.15	0.29	0	0	0	0	0.05	0.28	2.82	5.59	1.39	10.56
1x6	0	.10	.03	.26	.18	0	0	.40	3.82	9.73	1.41	15.94
1x8	.04	.08	.18	.47	.54	0	0	.20	6.15	9.55	.58	17.78
1x10	0	.11	0	.40	.16	0	.07	.65	9.20	9.66	.66	20.91
1x12	0	0	.08	1.61	1.19	0	.29	2.77	15.37	7.54	.62	29.48
5/4x4	0	0	0	0	0	0	0	0	0	.02	0	.02
5/4x6	0	0	0	0	0	0	0	0	.04	.04	0	.08
5/4x8	0	0	0	0	0	0	0	.13	.36	.11	0	.59
5/4x10	0	0	0	0	.06	0	0	.42	.58	.24	0	1.30
5/4x12	0	0	0	.09	.09	.37	0	1.68	.90	.21	0	3.34
Total	.18	.58	.29	2.82	2.23	.37	.41	6.54	39.23	42.68	4.67	100.00

Table 22--Total lumber production by dimension and grade--deterioration class III western white pine logs

Lumber dimension	C Select	D Select	3 Clear	1 Shop	2 Shop	3 Shop	1 Common	2 Common	3 Common	4 Common	5 Common	Total
Inches	Percent											
1x4	0.01	0.18	0	0	0	0	0.04	0.32	2.60	10.02	3.48	16.65
1x6	.03	.04	0	.05	.05	0	.09	.40	3.12	11.24	3.38	18.40
1x8	0	0	0	.12	.14	0	0	.10	2.44	9.39	2.36	14.54
1x10	0	0	0	.17	.06	0	0	.08	3.75	14.31	2.43	20.81
1x12	0	.05	0	.05	.48	0	0	.55	7.09	16.48	3.61	28.32
5/4x4	0	0	0	0	0	0	0	0	.03	.06	0	.09
5/4x6	0	0	0	0	0	0	0	.01	0	.05	0	.06
5/4x8	0	0	0	0	0	.04	0	.04	0	.10	0	.19
5/4x10	0	0	0	0	0	0	0	.08	.22	.10	0	.40
5/4x12	0	0	0	0	0	.07	0	0	.20	.27	0	.54
Total	.04	.27	0	.39	.73	.11	.14	1.58	19.46	62.03	15.26	100.00

Table 23--Total lumber production by dimension and grade--all deterioration classes, western white pine logs

Lumber dimension	C Select	D Select	3 Clear	1 Shop	2 Shop	3 Shop	1 Common	2 Common	3 Common	4 Common	5 Common	Total
Inches	Percent											
1x4	0.10	0.38	0	0	0	0	0.15	0.43	3.07	5.44	1.52	11.08
1x6	.04	.18	.02	.30	.11	0	.09	1.05	5.08	7.48	1.50	15.85
1x8	.03	.09	.06	.26	.31	0	.04	.57	5.94	7.20	.97	15.47
1x10	.01	.05	.03	.43	.10	0	.10	1.28	8.57	8.37	.95	19.88
1x12	.02	.01	.23	.84	.68	0	.21	2.77	13.69	9.40	1.41	29.26
5/4x4	0	.01	0	0	0	0	0	.01	.04	.04	0	.09
5/4x6	.01	.05	0	0	.03		0	.20	.14	.03	0	.45
5/4x8	.01	.07	0	.01	.06	.09	0	.65	.60	.09	0	1.58
5/4x10	.02	.08	0	.10	.07	.05	0	1.09	.97	.19	0	2.56
5/4x12	0	0	0	.10	.06	.16	0	2.10	1.17	.19	0	3.78
Total	.23	.92	.34	2.04	1.41	.30	.57	10.14	39.31	38.44	6.30	100.00

Table 24--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--live western white pine trees

Tree d.b.h.	Number of trees	Cubic volume[1/] Gross	Cubic volume[1/] Net	Cubic defect[2/]	Lumber tally volume	Lumber recovery factor[3/] Gross	Lumber recovery factor[3/] Net	Cubic volume[4/] Lumber	Cubic volume[4/] Sawdust	Cubic volume[4/] Residual	Cubic lumber recovery[5/] Gross	Cubic lumber recovery[5/] Net
		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--------Cubic feet-----			----Percent----	
10	1	12.80	11.80	7.8	26	2.03	2.20	2.23	.41	10.16	17	19
11	1	22.46	22.46	0	87	3.87	3.87	7.96	1.29	13.21	35	35
12	0	0	0	0	0	0	0	0	0	0	0	0
13	1	37.73	35.73	5.3	157	4.16	4.39	13.94	2.31	21.48	37	39
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	1	66.04	58.04	12.1	211	3.20	3.64	18.71	3.17	44.16	28	32
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	1	113.20	111.20	1.8	621	5.48	5.58	57.44	8.88	46.88	51	52
20	2	202.55	173.55	14.3	999	4.93	5.76	93.64	14.11	94.80	46	54
21	1	119.76	106.76	10.8	555	4.63	5.20	49.93	8.13	61.70	42	47
22	1	84.66	75.66	10.6	379	4.48	5.01	33.53	5.62	45.51	40	44
23	3	450.66	410.66	8.9	2,330	5.17	5.67	210.29	33.66	206.71	47	51
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	1	198.97	196.97	1.0	1,104	5.55	5.60	101.17	15.87	81.93	51	51
27	0	0	0	0	0	0	0	0	0	0	0	0
28	1	211.62	196.62	7.1	1,283	6.06	6.52	117.82	18.16	75.64	56	60
29	1	258.93	205.93	20.5	1,498	5.78	7.27	135.56	21.52	101.85	52	66
30	0	0	0	0	0	0	0	0	0	0	0	0
31	1	202.10	168.10	16.8	824	4.08	4.90	73.20	12.01	116.89	36	44
32	0	0	0	0	0	0	0	0	0	0	0	0
33	1	264.42	262.42	.8	1,657	6.27	6.31	149.23	23.80	91.39	56	57
Total or average	17	2,245.90	2,035.90	9.4	11,731	5.22	5.76	1,064.65	168.94	1,012.31	47	52

1/Gross volume is the total cubic volume of the tree from the stump to a 6-inch top; cubic volume was derived by Smalian's formula for all components except butt logs, which were calculated by Bruce's (1970a) formula. Net volume is equal to gross volume minus the net cubic defect estimate of each sawlog.

2/Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

3/Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

4/Lumber and sawdust volumes are based on rough green dimensions. Residual volume is equal to gross cubic volume of tree minus lumber and sawdust volumes.

5/Gross = (lumber cubic volume/gross tree cubic volume)(100); net = (lumber cubic volume/net tree cubic volume)(100).

Table 25--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--deterioration class I western white pine trees

Tree d.b.h.	Number of trees	Cubic volume[1] Gross	Cubic volume[1] Net	Cubic defect[2]	Lumber tally volume	Lumber recovery factor[3] Gross	Lumber recovery factor[3] Net	Cubic volume[4] Lumber	Cubic volume[4] Sawdust	Cubic volume[4] Residual	Cubic lumber recovery[5] Gross	Cubic lumber recovery[5] Net
		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--------Cubic feet-------			----Percent----	
9	2	22.67	21.67	4.4	48	2.12	2.22	4.05	0.73	17.89	18	19
10	0	0	0	0	0	0	0	0	0	0	0	0
11	1	27.85	27.85	0	107	3.84	3.84	9.70	1.57	16.58	35	35
12	0	0	0	0	0	0	0	0	0	0	0	0
13	4	152.62	135.62	11.1	682	4.47	5.03	56.78	10.27	85.57	37	42
14	2	91.46	84.46	7.7	409	4.47	4.84	35.41	6.21	49.84	39	42
15	3	173.47	152.47	12.1	612	3.53	4.01	52.87	9.13	111.47	30	35
16	2	127.30	101.30	20.4	410	3.22	4.05	36.27	6.26	84.77	28	36
17	8	628.12	542.12	13.7	2,702	4.30	4.98	242.49	42.49	343.14	39	45
18	3	256.02	224.02	12.5	1,191	4.65	5.32	103.98	17.85	134.19	41	46
19	5	464.41	413.41	11.0	2,160	4.66	5.22	190.94	32.10	241.37	41	46
20	3	292.81	263.81	9.9	1,447	4.94	5.48	128.39	21.43	142.99	44	49
21	5	660.86	591.86	10.4	3,422	5.18	5.78	300.82	50.54	309.50	46	51
22	5	726.97	680.97	6.3	3,848	5.29	5.65	343.27	56.45	327.25	47	50
23	4	595.17	498.17	16.3	3,062	5.14	6.15	237.61	45.32	312.24	40	48
24	5	742.39	691.39	6.9	4,148	5.59	6.00	364.12	61.69	316.58	49	53
25	0	0	0	0	0	0	0	0	0	0	0	0
26	1	220.80	160.80	27.2	938	4.24	5.83	81.50	14.13	125.12	37	51
27	4	756.25	632.25	16.4	3,766	4.98	5.96	330.34	55.76	370.15	44	52
28	1	169.78	143.78	15.3	832	7.90	5.78	73.06	12.25	84.47	43	51
29	3	646.12	521.12	19.4	3,148	4.87	6.04	280.19	45.92	320.01	43	54
Total or average	61	6,755.07	5,887.07	12.8	32,932	4.88	5.59	2,871.79	490.10	3,393.18	43	49

[1] Gross volume is the total cubic volume of the tree from the stump to a 6-inch top; cubic volume was derived by Smalian's formula for all components except butt logs, which were calculated by Bruce's (1970a) formula. Net volume is equal to gross volume minus the net cubic defect estimate of each sawlog.

[2] Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[3] Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[4] Lumber and sawdust volumes are based on rough green dimensions. Residual volume is equal to gross cubic volume of tree minus lumber and sawdust volumes.

[5] Gross = (lumber cubic volume/gross tree cubic volume)(100); net = (lumber cubic volume/net tree cubic volume)(100).

Table 26--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--deterioration class II western white pine trees

Tree d.b.h.	Number of trees	Cubic volume[1] Gross	Cubic volume[1] Net	Cubic defect[2]	Lumber tally volume	Lumber recovery factor[3] Gross	Lumber recovery factor[3] Net	Cubic volume[4] Lumber	Cubic volume[4] Sawdust	Cubic volume[4] Residual	Cubic lumber recovery[5] Gross	Cubic lumber recovery[5] Net
		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--------Cubic feet-------			----Percent----	
9	1	12.24	11.24	8.2	22	1.80	1.96	1.89	0.37	9.98	15	17
10	1	20.68	20.68	0	64	3.09	3.09	5.42	1.02	14.24	26	26
11	1	22.85	22.85	0	51	2.23	2.23	4.22	.76	17.87	18	18
12	2	70.25	67.25	4.3	261	3.72	3.88	22.36	4.05	43.84	32	33
13	1	31.97	30.97	3.1	133	4.16	4.29	11.41	2.05	18.51	36	37
14	3	136.04	84.04	38.2	294	2.16	3.50	24.92	4.57	106.55	18	30
15	2	116.01	99.01	14.6	409	3.52	4.13	35.00	6.28	74.73	30	35
16	1	70.30	55.30	21.3	326	4.64	5.90	28.21	4.99	37.10	40	51
17	4	286.27	247.27	13.6	1,177	4.11	4.76	100.84	17.79	167.64	35	41
18	2	179.35	153.35	14.5	710	3.96	4.63	61.93	10.60	106.82	34	40
19	2	182.24	150.24	17.6	838	4.60	5.58	72.16	12.78	97.30	40	48
20	2	190.27	157.27	17.3	800	4.20	5.09	69.05	11.97	109.25	36	44
21	2	181.56	153.56	15.4	753	4.15	4.90	66.61	11.05	103.90	37	43
22	1	103.41	70.41	31.9	341	3.30	4.84	30.07	5.12	68.22	29	43
23	2	245.30	211.30	13.9	1,356	5.53	6.42	117.74	20.36	107.20	48	56
24	4	550.26	448.26	18.5	2,760	5.02	6.16	240.15	41.05	269.06	44	54
25	1	175.07	147.07	16.0	804	4.59	5.47	70.18	11.96	92.93	40	48
26	4	620.34	448.34	27.7	2,714	4.38	6.05	238.18	40.44	341.72	38	53
27	2	384.02	314.02	18.2	2,109	5.49	6.72	181.93	31.67	170.42	47	58
28	2	545.25	425.25	22.0	2,782	5.10	6.54	245.28	41.26	258.71	45	58
29	1	177.36	125.36	29.3	452	2.55	3.60	39.96	6.65	130.75	22	32
30	0	0	0	0	0	0	0	0	0	0	0	0
31	1	285.17	201.17	29.5	1,087	3.81	5.40	95.10	16.05	174.02	33	47
32	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0
34	1	306.74	212.74	30.6	1,044	3.40	4.91	91.47	15.51	199.76	30	43
Total or average	43	4,892.95	3,856.95	21.2	21,287	4.35	5.52	1,854.08	318.35	2,720.52	38	48

[1] Gross volume is the total cubic volume of the tree from the stump to a 6-inch top; cubic volume was derived by Smalian's formula for all components except butt logs, which were calculated by Bruce's (1970a) formula. Net volume is equal to gross volume minus the net cubic defect estimate of each sawlog.

[2] Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

[3] Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

[4] Lumber and sawdust volumes are based on rough green dimensions. Residual volume is equal to gross cubic volume of tree minus lumber and sawdust volumes.

[5] Gross = (lumber cubic volume/gross tree cubic volume)(100); net = (lumber cubic volume/net tree cubic volume)(100).

Table 27--Summary of log scale, lumber recovery, and cubic volumes by 1-inch diameter classes--deterioration class III western white pine trees

Tree d.b.h.	Number of trees	Cubic volume[1/] Gross	Cubic volume[1/] Net	Cubic defect[2/]	Lumber tally volume	Lumber recovery factor[3/] Gross	Lumber recovery factor[3/] Net	Cubic volume[4/] Lumber	Cubic volume[4/] Sawdust	Cubic volume[4/] Residual	Cubic lumber recovery[5/] Gross	Cubic lumber recovery[5/] Net
		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--------Cubic feet-------			----Percent----	
9	2	23.45	19.45	17.1	36	1.54	1.85	2.87	0.56	20.02	12	15
10	2	42.66	37.66	11.7	128	3.00	3.40	10.76	1.86	30.04	25	28
11	3	66.92	52.92	20.9	126	1.88	2.38	10.64	1.92	54.36	16	20
12	2	70.46	56.46	19.9	198	2.81	3.51	16.67	3.08	50.71	24	30
13	4	145.35	138.35	4.8	489	3.36	3.53	41.65	7.64	96.06	29	30
14	0	0	0	0	0	0	0	0	0	0	0	0
15	4	189.38	161.38	14.8	435	2.30	2.70	37.08	6.76	145.54	20	23
16	5	326.09	277.09	15.0	1,275	3.91	4.60	109.65	19.45	196.99	34	40
17	4	272.96	218.96	19.8	943	3.45	4.31	81.21	14.45	177.30	30	37
18	4	338.16	276.16	18.3	1,319	3.90	4.78	113.82	20.25	204.09	34	41
19	5	432.84	287.84	33.5	1,350	3.12	4.69	116.07	20.68	296.09	27	40
20	7	716.05	509.05	28.9	2,739	3.82	5.38	235.45	41.61	438.99	33	46
21	3	341.39	306.39	10.2	1,660	4.86	5.42	142.66	25.21	173.52	42	47
22	2	236.97	204.97	13.5	869	3.67	4.24	75.53	12.87	148.57	32	37
23	7	908.81	635.81	30.0	3,448	3.79	5.42	296.61	52.33	559.87	33	47
24	1	128.18	107.18	16.4	491	3.83	4.58	42.29	7.25	78.64	33	39
25	3	509.01	398.01	21.8	2,060	4.05	5.18	178.17	31.19	299.65	35	45
26	4	681.92	461.92	32.3	2,232	3.27	4.83	192.39	34.67	454.86	28	42
27	4	823.40	601.40	27.0	3,193	3.88	5.31	275.40	48.32	499.68	33	46
28	3	636.96	455.96	28.4	2,803	4.40	6.15	240.81	42.41	353.74	38	53
29	2	445.07	332.07	25.4	2,297	5.16	6.92	198.96	32.42	213.69	45	60
30	0	0	0	0	0	0	0	0	0	0	0	0
31	2	453.66	322.66	28.9	1,399	3.08	4.34	120.54	21.22	311.90	27	37
Total or average	73	7,789.69	5,861.69	24.8	29,490	3.79	5.03	2,539.23	446.15	4,804.31	33	43

1/Gross volume is the total cubic volume of the tree from the stump to a 6-inch top; cubic volume was derived by Smalian's formula for all components except butt logs, which were calculated by Bruce's (1970a) formula. Net volume is equal to gross volume minus the net cubic defect estimate of each sawlog.

2/Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

3/Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

4/Lumber and sawdust volumes are based on rough green dimensions. Residual volume is equal to gross cubic volume of tree minus lumber and sawdust volumes.

5/Gross = (lumber cubic volume/gross tree cubic volume)(100); net = (lumber cubic volume/net tree cubic volume)(100).

Table 28--Summary of log scale, lumber recovery, and cubic volumes by 1-inch classes--all deterioration classes, western white pine trees

Tree d.b.h.	Number of trees	Cubic volume[1/] Gross	Cubic volume[1/] Net	Cubic defect[2/]	Lumber tally volume	Lumber recovery factor[3/] Gross	Lumber recovery factor[3/] Net	Cubic volume[4/] Lumber	Cubic volume[4/] Sawdust	Cubic volume[4/] Residual	Cubic lumber recovery[5/] Gross	Cubic lumber recovery[5/] Net
		--Cubic feet--		Percent	Board feet	Board feet per cubic foot		--------Cubic feet-------			----Percent----	
9	5	58.36	52.36	10.3	106	1.82	2.02	8.81	1.66	47.89	15	17
10	4	76.14	70.14	7.9	218	2.86	3.11	18.41	3.29	54.44	24	26
11	6	140.08	126.08	10.0	371	2.65	2.94	32.52	5.54	102.02	23	26
12	4	140.71	123.71	12.1	459	3.26	3.71	39.03	7.13	94.55	28	32
13	10	367.67	340.67	7.3	1,461	3.97	4.29	123.78	22.27	221.62	34	36
14	5	227.50	168.50	25.9	703	3.09	4.17	60.33	10.78	156.39	27	36
15	9	478.86	412.86	13.8	1,456	3.04	3.53	124.95	22.17	331.74	26	30
16	9	589.73	491.73	16.6	2,222	3.77	4.52	192.84	33.87	363.02	33	39
17	16	1,187.35	1,008.35	15.1	4,822	4.06	4.78	424.54	74.73	688.08	36	42
18	9	773.53	653.53	15.5	3,220	4.16	4.93	279.73	48.70	445.10	36	43
19	13	1,192.69	962.69	19.3	4,969	4.17	5.16	436.61	74.44	681.64	37	45
20	14	1,401.68	1,103.68	21.3	5,985	4.27	5.42	526.53	89.12	786.03	38	48
21	11	1,303.57	1,158.57	11.1	6,390	4.90	5.52	560.02	94.93	648.62	43	48
22	9	1,152.01	1,032.01	10.4	5,437	4.72	5.27	482.40	80.06	589.55	42	47
23	16	2,199.94	1,755.94	20.2	10,196	4.63	5.81	862.25	151.67	1,186.02	39	49
24	10	1,420.83	1,246.83	12.2	7,399	5.21	5.93	646.56	109.99	664.28	46	52
25	4	684.08	545.08	20.3	2,864	4.19	5.25	248.35	43.15	392.58	36	46
26	10	1,722.03	1,268.03	26.4	6,988	4.06	5.51	613.24	105.11	1,003.68	36	48
27	10	1,963.67	1,547.67	21.2	9,068	4.62	5.86	787.67	135.75	1,040.25	40	51
28	7	1,563.61	1,221.61	21.9	7,700	4.92	6.30	676.97	114.08	772.56	43	55
29	7	1,527.48	1,184.48	22.4	7,395	4.84	6.24	654.67	106.51	766.30	43	55
30	0	0	0	0	0	0	0	0	0	0	0	0
31	4	940.93	691.93	26.5	3,310	3.52	4.78	288.84	49.28	602.81	31	42
32	0	0	0	0	0	0	0	0	0	0	0	0
33	1	264.42	262.42	.8	1,657	6.27	6.31	149.23	23.80	91.39	56	57
34	1	306.74	212.74	30.6	1,044	3.40	4.91	91.47	15.51	199.76	30	43
Total or average	194	21,683.61	17,641.61	18.6	95,440	4.40	5.41	8,329.75	1,423.54	11,930.32	38	47

1/Gross volume is the total cubic volume of the tree from the stump to a 6-inch top; cubic volume was derived by Smalian's formula for all components except butt logs, which were calculated by Bruce's (1970a) formula. Net volume is equal to gross volume minus the net cubic defect estimate of each sawlog.

2/Equals (gross cubic scale - net cubic scale/gross cubic scale)(100).

3/Gross = (lumber tally volume/gross cubic scale); net = (lumber tally volume/net cubic scale).

4/Lumber and sawdust volumes are based on rough green dimensions. Residual volume is equal to gross cubic volume of tree minus lumber and sawdust volumes.

5/Gross = (lumber cubic volume/gross tree cubic volume)(100); net = (lumber cubic volume/net tree cubic volume)(100).

Snellgrove, Thomas A., and James M. Cahill.
1980. Dead western white pine: characteristics, product recovery, and problems associated with utilization. USDA For. Ser. Res. Pap. PNW-270, 63 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

When a western white pine (*Pinus monticola* Dougl. ex D. Don) tree dies, it undergoes a series of physical changes. The effects of these changes on product recovery are evaluated. Tabular information and prediction equations provide the tools necessary for using this resource.

KEYWORDS: Dead timber, lumber recovery, lumber yield, wood utilization, deterioration (wood), western white pine (dead), *Pinus monticola*.

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